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Phenotypic Performance Profile of Children With Reading Disabilities: A Regression-Based Test of the Phonological-Core Variable-Difference Model

Keith E. Stanovich and Linda S. Siegel

In this study, we introduce a new analytic strategy for comparing the cognitive profiles of children developing reading skills at different rates: a regression-based logic that is analogous to the reading-level match design, but one without some of the methodological problems of that design. It provides a unique method for examining whether the reading subskill profiles of poor readers with aptitude/achievement discrepancy differ from those without discrepancy. Children were compared on a varied set of phonological, orthographic, memory, and language processing tasks. The results indicated that cognitive differences between these 2 groups of poor readers all reside outside of the word recognition module. The results generally support the phonological-core variable-difference model of reading disability and demonstrate that degree of aptitude/achievement discrepancy is unrelated to the unique cognitive tradeoffs that are characteristic of the word recognition performance of children with reading disabilities.

Scientific reduction is the process whereby the laws and theoretical concepts at one level of analysis are mapped onto the laws and concepts of a more basic level of scientific analysis (Churchland, 1979). The phenomenon of reading disability has been the subject of several such reductive efforts in the past decade. Investigators have attempted to characterize the functional neurophysiology of reading disability and to localize the information-processing deficits in certain parts of the brain of readers with dyslexia (e.g., Duane & Gray, 1991; Galaburda, 1991; Hynd, Marshall, & Gonzalez, 1991; Larsen, Hoien, Lundberg, & Odegaard, 1990; Steinmetz & Galaburda, 1991). Other researchers have attempted to analyze the genetics of dyslexia and to estimate the heritability of information-processing operations that are particularly deficient in people with dyslexia (e.g., Olson, Wise, Conners, Rack, & Fulker, 1989; Pennington, Gilger, Olson, & DeFries, 1992; Plomin, 1991). More indirectly reductive research programs are being carried out by investigators who are attempting to model dyslexic performance patterns with connectionist computer models (e.g., Hinton & Shallice, 1991; Seidenberg, 1992; Seidenberg & McClelland, 1989; Van Orden, Pennington, & Stone, 1990). All of these reductive efforts are completely dependent on an accurate characterization of the phenotypic performance pattern of children with reading disabilities. For these research programs to succeed, researchers must first know who is reading disabled and must second, determine what is unique about the information-processing characteristics of these individuals. Quite simply, investigators engaged in reductive research programs must know whose brain to scan, whom to do a postmortem autopsy on, whose family to subject to linkage analysis, which tasks to subject to heritability analysis, and which performance patterns to try to mimic with computer models.

The behavioral phenomenon of dyslexia presents a problem for reductive research efforts because the classification criteria for the condition have long been in dispute (Ceci, 1986; Morrison, 1991; Rutter, 1978; Siegel, 1988, 1989; Siegel & Heaven, 1986; Stanovich, 1986a, 1991a; Vellutino, 1978). Equally contentious has been the ongoing debate regarding which processing deficiencies are uniquely characteristic of children with reading disabilities (cf. Bruck, 1988, 1990; Lovegrove, 1992; Morrison, 1987, 1991; Olson, Kliegl, Davidson, & Foltz, 1985; Olson et al., 1989; Pennington, 1986; Siegel, 1992, 1993; Siegel & Ryan, 1988; Stanovich, 1986a, 1988b; Tallal, Sainburg, & Jernigan, 1991; Vellutino, 1979; Willows, 1991; Wolf, 1991). Reductive research efforts will continue to be hampered (indeed, such efforts may even be premature) until researchers succeed in coming to a consensual model of reading disability classification and until they can definitively establish what is unique about the cognitive processing profile of children with reading disabilities. For example, Pennington (1986) noted, "Powerful genetic techniques are becoming increasingly available for the study of inherited, complex behavior disorders, including learning disabilities. Yet the utility of these techniques is directly affected by how we define the behavioral phenotype in question" (p. 69).

Definitional Problems: The Issue of IQ Discrepancy

The questions of who is reading disabled and which cognitive profile characterizes reading disability seem to be

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Correspondence concerning this article should be addressed to either Keith E. Stanovich or Linda S. Siegel, Department of Applied Psychology, Ontario Institute for Studies in Education, 252 Bloor Street West, Toronto, Ontario, Canada M5S 1V6.

separate. However, these issues have actually become conjoined because of the strange "cart-before-the-horse" history that has characterized the reading disabilities field (Stanovich, 1991a). One might have thought that researchers would have begun with the broadest and most theoretically neutral definition of reading disability—reading performance below some specified level on some well-known and psychometrically sound test—and then proceeded to investigate whether there were poor readers with differing cognitive profiles within this broader group. Unfortunately, the history of reading disabilities research does not resemble this logical sequence. Instead, in early definitions of reading disability, researchers assumed that there was a differential cognitive profile (and causation) within the larger sample of poor readers and defined the condition of reading disability in a way that actually precluded empirical investigation of the unproven theoretical assumptions that guided the formulation of these definitions.

This remarkable sleight of hand was achieved by tying the definition of reading disability to the notion of aptitude–achievement discrepancy (Ceci, 1986; Reynolds, 1985; Shepard, 1980; Siegel, 1989; Stanovich, 1991a); that is, it was assumed that poor readers of high aptitude—as indicated by IQ test performance—were cognitively and neurologically different from poor readers of low aptitude. The terms *dyslexia*, or *reading disability*, were reserved for those children showing statistically significant discrepancies between reading ability and intelligence test performance. Such discrepancy definitions have become embedded in the legal statutes governing special education practice in many states of the United States (Frankenberger & Fronzaglio, 1991; Frankenberger & Harper, 1987), and they also determine the subject selection procedures in most research investigations (Stanovich, 1991a). The critical assumption that was reified in these definitions—in the almost total absence of empirical evidence—was that degree of discrepancy from IQ was meaningful; that is, that the reading difficulties of children with reading disabilities and high aptitude (i.e., children with a discrepancy) were different from those characterizing children with reading disabilities and low aptitude (i.e., children without a discrepancy).

One reason that the study of reading disability has remained so confusing is that, until quite recently, researchers have lacked empirical evidence that validated the basic assumption that was driving classification of children for purposes of research and educational practice. In fact, the utility of aptitude–achievement discrepancy for understanding the cognitive basis of reading disability remains to be demonstrated. Ironically, the dominance of the discrepancy assumption has sometimes precluded the collection of the relevant data. Obviously, from the beginning, researchers should have made sure to include children with and without an aptitude–achievement discrepancy in their samples so that the discrepancy assumption could be tested. Instead, the discrepancy notion became reified so quickly in practice that researchers often culled children without a discrepancy from their samples to attain more homogeneous groups, thus precluding the critical comparison of children with and without a discrepancy.

Thus, for many years, most investigations of reading disabilities did not include children without an aptitude–achievement discrepancy as controls. These investigations provided no indication of whether children without a discrepancy would have shown the same cognitive pattern as the children with a discrepancy, who were the focus of the investigation. Rutter and Yule's (1975) ground-breaking investigation of differences between children with and without a discrepancy stood alone for nearly a decade. Only recently have a number of converging studies that included children without a discrepancy as controls been reported (Fletcher et al., 1989; Fletcher, Francis, Rourke, Shaywitz, & Shaywitz, 1992; Fletcher et al., 1994; Jorm, Share, Maclean, & Matthews, 1986; Pennington et al., 1992; Shaywitz, Fletcher, Holahan, & Shaywitz, 1992; Siegel, 1988, 1989, 1992).

Differences in the Processing Profile of Children With Reading Disabilities

The issue of whether there are cognitive differences between children with and without an aptitude–achievement discrepancy is related to the issue of whether the reading-related cognitive processes of individuals with reading disabilities develop in ways different from those of readers without disabilities or whether the cognitive processes go through the same sequence of stages at a slower rate (the latter situation is sometimes characterized as a developmental lag—see Stanovich, Nathan, & Vala-Rossi, 1986). This question of differential sequence or developmental lag can be investigated—and can potentially yield different answers—for groups of children with as well as for samples children without a discrepancy. In traditional discrepancy-based definitions, it is assumed that there is a differential outcome for the two groups (Stanovich, 1988a, 1991a)—one in which the group without a discrepancy displays a developmental lag and one in which the group with a discrepancy displays a unique cognitive developmental sequence. However, there is little evidence regarding this critical assumption; therefore, we examine the developmental lag versus deficit issue.

One way to address the question of whether children with reading disabilities are characterized by differences in developmental sequence is by examining cognitive profiles in a reading-level matched design. The reading-level match design is one in which an older group of children with reading disabilities is compared with a younger group of children without reading disabilities who are matched on reading level (Backman, Mamen, & Ferguson, 1984; Bisanz, Das, & Mancini, 1984; Bradley & Bryant, 1978; Guthrie, 1973; Snowling, 1980). In the mid-1980s this design underwent a dramatic increase in popularity because it is more selective than the traditional chronological-age match design in isolating processing differences between children with and without reading disabilities. When children with reading disabilities are compared with chronological-age matched controls, it is well known that they display significant differences on a multiplicity of tasks (e.g., Stanovich, 1986a), thereby reducing the diagnosticity of any single difference (Bryant & Goswami, 1986; Goswami & Bryant, 1989). A particular difference in a chronological-age match design is thus open to an unusually large number of alternative explanations (Bryant & Goswami, 1986), including the very real possibility that the processing difference is the result of the different reading experiences of the two groups (Stanovich, 1986b; 1993a). In contrast, the number of tasks on which children with reading disabilities display deficits relative to reading-level controls is much smaller. Additionally, any differences that are observed cannot be the result of differences in reading ability between the groups because the design eliminates such differences.

Nevertheless, when viewed as a diagnostic tool to test whether a particular variable is causally linked to reading disability—in other words, when viewed as a sort of quasi-experiment—the reading-level match design is fraught with methodological and statistical complications (Goswami & Bryant, 1989; Jackson & Butterfield, 1989). For example, regression artifacts are particularly prone to obscure inferences about single variables (see Jackson & Butterfield, 1989). The previous focus on the design as a kind of quasi-experimental method to test a causal hypothesis about a single variable (e.g., Backman et al., 1984; Bradley & Bryant, 1978; Bryant & Goswami, 1986) seems to have been misdirected (see Jackson & Butterfield, 1989). However, as a context for the comparison of cognitive profiles in a multivariate study, the design can still be of great utility (e.g., Bowey, Cain, & Ryan, 1992; Olson, Wise, Conners, & Rack, 1990; Siegel & Ryan, 1988; Stanovich, Nathan, & Zolman, 1988; Vellutino & Scanlon, 1987, 1989). For example, it provides one way to operationalize the question of whether readers progressing at different rates are going through the same developmental stages. If they are, then relationships among cognitive subskills should be the same for older readers with disabilities as they are for younger readers without disabilities at the same reading level. Any imbalance in cognitive subskills that appears when the two groups are compared is an indication that they must be reaching their similar levels of reading skills in different ways. Provided that there is independent evidence from other types of designs indicating that the skills examined in the multivariate profile are indeed linked to reading ability, then mismatched cognitive profiles in a reading-level study are an empirical indication that the developmental paths by which the two groups came to their similar reading levels must be different. Note that this outcome is agnostic regarding the issue of what might be the cause of the different developmental paths—for which there may be many alternative explanations.

This use of the reading-level match design—as an operationalization of developmental pattern differences in reading progress among children differing in rate of progress—is a more modest and less conceptually complex use of the design than its more customary use as a quasi-experimental test of a causal hypothesis concerning a single variable. It is the latter usage that has been the subject of the most intense methodological criticism. In contrast, Olson et al. (1990) have argued for the usefulness of the reading-level match design in the former, more descriptive, manner.

> Our assumptions about the matching paradigm are modest. We do not assume that the groups are equivalent in reading experience, or that a deficit in a component skill would necessarily imply a causal role for reading disability, or that a deficit would imply its constitutional origin. . . . It is of interest to see whether the profiles of component skills are similar or different for the two groups. . . . Converging evidence would be required to determine the causal role and etiology of any significant deficits. (p. 272)

Similarly, Jackson and Butterfield (1989) noted that "An RL [reading-level] match is more sensitive for determining whether fast- and slow-progressing readers are more different in some aspects of their performance than in others" (p. 397).

As Jackson and Butterfield (1989) have argued, the results of a reading-level study

> need not imply any causal direction for the relationship between rate and skill pattern, but investigators often want to draw some directional, causal implications from their findings. Although one could think of rate of progress as determining skill patterns, directional hypotheses usually are concerned with the reverse possibility. (p. 388)

In the present investigation—an attempt to characterize the phenotypic processing pattern of children with and without aptitude–achievement discrepancy—we are not primarily concerned with the reverse possibility. Instead, we use the design for the former, more modest, purpose: to answer the straightforward operational question of whether children with and without reading disabilities differ in pattern of cognitive skills.

A New Analytic Strategy for the Reading-Level Match Design

However, there remain obstacles in using the reading-level match design for even the purpose proposed here: identification of differences in cognitive patterns among children differing in rate of progress. Although some conceptual problems associated with the quasi-experimental use of the reading-level match design are eliminated, other statistical problems, such as the possibility of regression artifacts, remain (Jackson & Butterfield, 1989). Additionally, such studies present investigators with many logistical problems. It is difficult for many investigators to procure enough matched subjects at any one age level to ensure a powerful statistical test. This forces many investigators to collapse subjects across rather wide age ranges (e.g., Snowling, Stackhouse, & Rack, 1986), thus introducing possibly confounding variables. Problems with subject procurement have precluded most investigators from examining reading-level matches at more than one reading level (see Bisanz et al., 1984, Siegel & Ryan, 1988, and Szeszulski & Manis, 1987, for exceptions), and rarely have investigators included in reading-level studies children with and children without an aptitude–achievement discrepancy who were poor readers. The latter is a particularly important missing dimension in investigations of reading disability; one that we attempt to remedy here by reporting a reading-level match comparison of children with and without a discrepancy.

We introduce in this report an analytic logic that removes many of the statistical artifacts of matched-groups reading-level designs and that simultaneously allows investigators to use subjects over a wide range of reading levels in their study while still attaining the empirical comparison that is the desired result of the traditional reading-level design. We reconceptualize the entire logic of the reading-level design into the continuous framework of regression analysis. Other investigators have suggested reframing reading-level designs within a continuous framework (Bryant & Goswami, 1986; Jackson & Butterfield, 1989; Mamen, Ferguson, & Backman, 1986) but, to our knowledge, no investigation has used the procedure that we describe.

Our sample consisted of a large group of children whose reading level spanned a grade equivalent range of 1.0 (Grade 1, 0 months) to 5.8 (Grade 5, 8 months) on a standardized test of word recognition ability (the Reading subtest of the Wide Range Achievement Test—Revised; WRAT–R; J. Jastak & Jastak, 1978; S. Jastak & Wilkinson, 1984). Within this sample, we defined three groups of readers:[1] Group 1 consisted of children whose reading achievement was consistent with that of their age cohort (controls). Group 2 comprised children with a significant aptitude–achievement discrepancy in reading performance. Group 3 included children without an aptitude–achievement discrepancy who were reading significantly below their grade level. Children in Groups 2 and 3 are significantly older than the children in Group 1 and, as a function of the selection criteria, children in Groups 1 and 3 had IQs significantly higher than those of the children in Group 2.

Using a large set of theoretically relevant criterion variables, we examined the performance of all three groups within this range of reading levels together in one regression analysis that has the following components. We regressed the criterion variable on WRAT–R reading grade level (and all significant power polynomials), thus removing all of the variance in the criterion variable that is associated with overall reading level. Subsequent to entering WRAT–R reading level, we simultaneously entered two contrasts reflecting the group classifications into the equation: one contrast capturing the comparison of children with versus children without reading disabilities (Groups 2 and 3 vs. Group 1) and the comparison of children with versus children without an aptitude–achievement discrepancy (Group 2 vs. Group 3). To whatever extent the criterion variable is associated with group classification independent of overall reading level, it will be reflected in significant beta weights (and explained variance) for these contrasts (see Cohen & Cohen, 1983; Darlington, 1990; Keppel & Zedeck, 1989). A significant beta weight for the first contrast becomes analogous to a processing deficit (or advantage, depending on the sign) in a more traditional—and methodologically problematic—matched-groups reading-level design. A significant beta weight for the second contrast indicates that the performance of Group 2 differs from that of Group 3 when they are statistically equated on WRAT–R Reading level. Alternatively, if performance on a variable tracks reading level, independent of the age at which children reach a given reading level or independent of the IQ of the reader, then subject classification (i.e., Group 1, Group 2, Group 3) should not be a significant predictor once reading level has been removed. In short, if a developmental lag model characterizes all poor readers, then once the variance due to reading level is regressed out as a predictor of a reading-related cognitive subskill, subject categorization should not predict additional variance in the criterion variable.

Ours is a continuous, regression-based equivalent of the reading-level design that has several advantages as an analytic strategy: (a) the logistical advantage of allowing subjects to be combined across several reading levels because there is no necessity to create a matched group at each reading level to examine them, (b) increased representativeness of the samples because case-by-case matching of subgroups on reading level is not required, and (c) freedom from the regression confounds that plague the traditional matched extreme-groups reading-level design. As Jackson and Butterfield (1989) argued,

> For purposes of maximizing external validity, statistical matching has at least two advantages over matching by sample selection. First, all samples will be representative of real populations whose identification can be replicated. Second, one can analyze data using several different statistical procedures to see whether the pattern of results remains consistent with the same theoretical model. (p. 398)

Previous investigations using the reading-level design have been precluded from using the discrepant–nondiscrepant criterion, in part, because the selection requirements of an additional category often prohibitively increase the number of matched subjects that the investigator must procure from a single grade level. Our analytic strategy allows the investigator to more easily embed a comparison between Group 2 and Group 3 children into reading-level designs. The ability to combine subjects across several reading levels makes it easier to attain the requisite sample sizes within each of the psychometrically constrained groups with reading disabilities. In our methodology, the comparison between Group 2 and Group 3 is created by analyzing the independent contribution of an additional vector that is entered into the regression equation along with the basic contrast between children with and without disabilities. When the two contrast vectors are entered simultaneously into the regression equation along with WRAT reading level (these two vectors are not orthogonal because the groups have unequal *N* values; see Keppel & Zedeck, 1989), the regression coefficient of the first vector reflects the variance associated with the with disability versus without disability classification independent of the discrepancy distinction and reading level. The second vector reflects the variance in the criterion variable associated with the discrepant–nondiscrepant distinction independent of the with versus without disability distinction and reading level. Thus, a test of the IQ-discrepancy assumption is captured in a design that is the

[1] Using the method to be described, various selection criteria can be explored within the same sample. Different cutoff values for reading disability can be examined (e.g., different percentile ranks on the reading test used) as well as several different methods of defining aptitude–achievement discrepancy (e.g., absolute IQ cutoff score, standard score discrepancy, and regression discrepancy). Some of the results of employing these alternative criteria are reported later.

logical equivalent of the traditional matched-groups reading-level design.

Theoretical Context for the New Analytic Strategy

A theoretical context for our analytic strategy is provided by the phonological-core variable-difference model of reading disability (Siegel, 1992; Stanovich, 1988a). The model provides a conceptualization within which to work out the implications of traditional definitions of dyslexia (Stanovich, 1991a). For example, traditional definitions rest on the assumption that groups of children with reading disabilities defined by aptitude–achievement discrepancies have a brain or cognitive deficit that is reasonably specific to the reading task. The assumptions that are commonly made about the IQ tests used to create the Group 2 category—and the psychometric logic involved—virtually require that the deficits displayed by such children not extend too far into other domains of cognitive functioning. If they did extend into too many other domains, the probability that these domains would overlap with the constellation of abilities tapped by IQ tests would increase and the reading–intelligence discrepancy that defines this category of poor reader would disappear.

In short, standard psychometric assumptions seem to require that the deficits displayed by the children in Group 2 must display some degree of modularity and domain specificity, whereas this is not true for children in Group 3. For this reason and for other reasons, many investigators have located the proximal problem of Group 2 children at the word recognition level (e.g., Adams & Bruck, 1993; Bruck, 1988, 1990; Gough & Tunmer, 1986; Morrison, 1987; Perfetti, 1985; Siegel, 1988; Siegel & Faux, 1989; Stanovich, 1986b) and have been searching for the locus of the flaw in the word recognition module.

In the last 10 years researchers have focused intensively on phonological processing abilities and have found that children with dyslexia display deficits in various aspects of phonological processing. Children with dyslexia have difficulty making explicit reports about sound segments at the phoneme level; they display naming difficulties; their use of phonological codes in short-term memory is inefficient; their categorical perception of certain phonemes may be other than normal; and they may have speech production difficulties (e.g., Bentin, 1992; Bowey et al., 1992; Bradley & Bryant, 1978; Bruck, 1992; Bruck & Treiman, 1990; Goswami & Bryant, 1990; Kamhi & Catts, 1989; Lieberman, Meskill, Chatillon, & Schupack, 1985; Olson et al., 1989; Pennington, 1986; Perfetti, 1985; Snowling, 1991; Stanovich, 1986b, 1992; Taylor, Lean, & Schwartz, 1989; Tunmer & Hoover, 1992; Wagner & Torgesen, 1987; Williams, 1986; Wolf, 1991). Importantly, there is increasing evidence that the linkage from phonological processing ability to reading skill is a causal one (e.g., Ball & Blachman, 1991; Bradley & Bryant, 1985; Byrne & Fielding-Barnsley, 1993; Cunningham, 1990; Hatcher, Hulme, & Ellis, in press; Iverson & Tunmer, 1993; Lie, 1991; Lundberg, Frost, & Peterson, 1988; Mann, 1993; Torgesen, Morgan, & Davis, 1992). Whether all of these phonologically related deficits are reflective of a single underlying processing problem and whether all of them can be considered causal rather than correlative is a matter for future research, but some important progress is being made on these issues (e.g., Fowler, 1991; Hansen & Bowey, in press; Pennington, Van Orden, Kirson, & Haith, 1991; Pennington, Van Orden, Smith, Green, & Haith, 1990; Wagner, Torgesen, & Rashotte, 1993; Wagner, Torgesen, & Rashotte, 1994).

In the phonological-core variable-difference model (Stanovich, 1988a), the term *variable difference* refers to the key performance contrasts between readers with and without an aptitude–achievement discrepancy outside of the phonological domain. Although children both with and without a discrepancy are assumed to share the phonological-core deficits that are the source of their word recognition problems, the child without a discrepancy may have deficits in a wider variety of processes that are linked to reading ability, and some of these (e.g., memory skills) are nonmodular processes. This framework provides an explanation for why almost all processing investigations of reading disability have uncovered phonological deficits, but also why some investigations have found deficits in many other areas as well (see Stanovich, 1988b). This outcome is predictable from the fact that the phonological-core variable-difference model posits that virtually all poor readers have a phonological deficit, but other processing deficits emerge as one drifts in the multidimensional space from children with a discrepancy toward children without a discrepancy. Presumably, the studies finding deficits extending beyond the phonological domain are those containing a greater proportion of children without a discrepancy. This follows from the model's more general prediction that differences between children with and without a discrepancy should increase as the processes tested become more central, less modular, and further removed from the phonological core. In contrast, both groups should look similar when tested on tasks that tap the phonological core deficit that they are assumed to share.

With these predictions of the phonological-core variable-difference model in mind, we have ordered the analyses of the criterion variables in our study in the following manner. We first wanted to demonstrate the logic of the analysis by examining performance on an achievement variable that would be expected to yield differences between older children with reading disabilities and younger children without reading disabilities and between poor readers with a high IQ and poor readers with a low IQ. We chose arithmetic performance as an example of a task likely to yield significance for both of the group classification contrasts in our regression analysis (presumably the older children without a discrepancy should outperform the younger controls). We then turned to a key theoretical distinction contained in most recent theories of reading disability: the characterization of individual differences in the relative trade-off between phonological and orthographic coding abilities. In a recent meta-analysis, Rack, Snowling, and Olson (1992) concluded that disabled readers with aptitude–achievement discrepancy display performance inferior to that of younger reading-level controls on the primary index of phonological coding ability: pseudoword reading. It is unclear whether this finding extends to poor readers without an aptitude–achievement discrepancy. Our second analysis concentrates on pseudoword processing to determine whether our results converge with the conclusions of the Rack et al. (1992) meta-analysis and whether the conclusion that there is a pseudoword deficit in a reading-level match design extends to poor readers without a discrepancy. We also examine some phonological coding tasks other than pseudoword reading.

Previous research has indicated that, compared with these phonological coding deficits, children with dyslexia seem to be relatively less disadvantaged in tasks that tap orthographic coding abilities (Holligan & Johnston, 1988; Levinthal & Hornung, 1992; Olson et al., 1985; Pennington et al., 1986; Rack, 1985; Siegel, 1993). There has even been suggestive evidence (see Siegel, 1993) that, in comparison with reading-level-matched controls, children with reading disabilities might display a processing superiority in orthographic coding. Examining a variety of orthographic tasks, we examine the evidence for this compensatory trade-off among processing subskills.

Relative differences in processing impairments in phonological and orthographic coding tasks can be interpreted either within the context of dual-route models of word recognition (Humphreys & Evett, 1985) or within the context of connectionist models (e.g., Seidenberg & McClelland, 1989). For example, a reading-level deficit in pseudoword reading (a task commonly thought to involve phonological coding) on the part of children with reading disabilities is easily interpreted within both frameworks. However, the suggestion that the same children display, simultaneously, spelling–sound regularity effects (commonly used as an indicator of phonological processing) that are equivalent to those displayed by reading-level matched controls (see Rack et al., 1992) is extremely problematic for dual-route models and may also be inconsistent with connectionist accounts. We examine this seemingly paradoxical processing pattern with our analytic strategy, which again, will demonstrate whether it holds for children with as well as for children without an aptitude–achievement discrepancy.

After exploring these subword processing components of reading, we examine reading-related processes beyond word recognition. Performance on a variety of memory and language processing tasks that are related to reading comprehension ability (as well as to word recognition ability) are analyzed. The analysis of performance on these tasks allows a critical prediction of the phonological-core variable-difference model of reading disability to be tested. In this model, performance differences between children with and children without a discrepancy are predicted to increase as the processes tested become more central, less modular, and further removed from the phonological core (Siegel, 1992; Stanovich, 1988a).

Method

Subjects

The analyses presented here amalgamated the data from children who participated in several previously published studies (e.g., Siegel, 1988; Siegel & Ryan, 1988) with the data from children participating in some more recent unpublished studies. The entire database was used for the subject partitioning to be described in the following paragraphs. However, different numbers of subjects completed each of the tasks. Some of the children were from schools in southern Ontario and were tested in their schools. Others came to a psychoeducational assessment clinic to participate in studies of reading-related cognitive processes. The children who came to the assessment clinic were from the same schools, classrooms, and neighborhoods as the children who were tested in the schools. Most of the school sample was achieving at grade-appropriate levels, whereas most of the assessment sample had some type of learning disability. Socioeconomically, the participants were predominantly middle class, and less than 2% were non-White. All were being educated in English and spoke English as their primary language. Children with neurological problems, English as a second language, severe behavioral deficits, and sensory deficits were excluded from the sample.

The total amalgamated sample consisted of over 1,500 children, aged 7 to 16 years. From this sample, we selected all children who were reading between grade levels 1.0 through 5.8 on the Reading subtest of the WRAT–R. These 907 children had all been administered at least one of the following IQ tests: Wechsler Intelligence Scale for Children—Revised (WISC–R; Wechsler, 1974), an abbreviated version of the WISC–R in which an estimated IQ score can be calculated from Vocabulary and Block Design (Sattler, 1982), or the Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 1981). If a full WISC–R was available, it was used as the IQ estimate. If not, the estimated IQ from the administration of the Vocabulary and Block Design subtests was used. If neither of these was available, the IQ estimate was based on the PPVT. Two hundred fifty-five subjects were classified on the basis of WISC–R Full Scale scores, 535 on the basis of the abbreviated WISC–R, and 117 on the basis of the PPVT. Results were virtually identical when analyses were carried out on groups defined by the same IQ test. Thus, the combined sample was used in the analyses that follow.

The children were classified into one of three groups: Group 1 subjects' percentile scores on the WRAT–R were ≥ 30. Group 2 subjects' percentile scores on the WRAT–R were ≤ 25 and their IQs were >90, and Group 3 subjects' percentile scores on the WRAT–R were ≤ 25 and their IQs were ≤ 90. When the IQ scores of children in Groups 2 and 3 were subtracted from their standard scores on the reading measure ($M = 100$, $SD = 15$), the mean discrepancy was 25.5 points for Group 2 and 0.5 points for Group 3.

For differentiating Groups 2 and 3 in our first set of analyses, we used an absolute IQ-cutoff criterion. First, we analyze all of the variables using this criterion. Then we present parallel analyses using two other methods of discrepancy classification: the standard score discrepancy method and the regression discrepancy method (see Fletcher et al., 1992; Reynolds, 1985; Shepard, 1980; Stevenson, 1992).

Table 1 displays the mean WRAT–R percentile score, estimated IQ, and age in months for each of the three groups at each of the five reading levels formed by combining all subjects at WRAT–R reading levels 1 through 5. From the table it is clear that Group 1 is performing at the WRAT–R level expected for its age (i.e., around the 50th percentile), whereas Groups 2 and 3 are both performing substantially below expectation for their chronological age (approximately the 10th percentile). Groups 1 and 2 have average IQ scores that are substantially higher than those of Group 3, which averages slightly below 80. Children in Groups 2 and 3 are chronologically over 2 years older than the children in Group 1, who are matched to them on reading level.

Table 1
Mean Reading Percentile, IQ, and Age as a Function of Subject Classification and Reading Grade Level on the Wide Range Achievement Test—Revised (WRAT–R)

	Group 1		Group 2		Group 3	
Variable	*M*	*n*	*M*	*n*	*M*	*n*
WRAT–R percentile						
Reading Grade Level 1	40.7	3	5.0	85	5.5	28
Reading Grade Level 2	47.0	56	10.2	114	6.8	49
Reading Grade Level 3	52.8	89	14.8	66	11.1	49
Reading Grade Level 4	55.9	134	14.1	50	9.6	24
Reading Grade Level 5	61.4	117	15.3	26	12.3	17
IQ score						
Reading Grade Level 1	106.7	3	106.5	85	73.3	28
Reading Grade Level 2	104.2	56	107.0	114	78.9	49
Reading Grade Level 3	102.8	89	102.6	66	79.2	49
Reading Grade Level 4	105.2	134	101.8	50	76.5	24
Reading Grade Level 5	104.7	117	104.3	26	81.4	17
Age (in months)						
Reading Grade Level 1	91.7	3	98.0	85	101.1	28
Reading Grade Level 2	91.0	56	112.5	114	121.1	49
Reading Grade Level 3	102.5	89	130.5	66	139.1	49
Reading Grade Level 4	112.3	134	147.1	50	157.5	24
Reading Grade Level 5	120.5	117	158.5	26	168.4	17

Note. Group 1 consists of children without an aptitude–achievement discrepancy who are reading at the level expected for their grade (controls). Group 2 comprises children with reading disabilities and with discrepancy. Group 3 is composed of children with reading disabilities and low aptitude (without a discrepancy). n = the number of subjects in each group.

Analysis

In the analyses that follow, a variety of different tasks are used as criterion variables. Because these data derive from several different studies, not all children were administered all tasks. When means are presented for all of the 15 Reading Level × Subject Classification Groups, it becomes apparent that, occasionally, some cells have a small number of subjects. However, because our analytic method is a continuous regression-based procedure, data from these cells are usable (Keppel & Zedeck, 1989) and are included in the analysis—unlike the matched-groups design with an analysis-of-variance (ANOVA) logic that complicates the use of small cell sizes. The 1984 WRAT–R uses the symbols B (beginning), M (middle), and E (end) to code parts of years in grade equivalents. To get a continuous numeric score, we coded B as 2, M as 5, and E as 8 so that, for example, a grade equivalent of 2B was coded as 2.2 and a grade equivalent of 5E was coded as 5.8.

The analysis begins by partialing from the criterion variable the linear trend of WRAT–R reading level and all significant higher order trends. After the variance associated with WRAT–R reading level is extracted, two nonorthogonal contrasts (see Keppel & Zedeck, 1989) are entered simultaneously into the regression equation. One contrast reflects the comparison between children with and children without reading disabilities. The coding for this contrast is +1 for Group 3 and Group 2 children, and it is −1 for Group 1 children. A positive beta weight for this contrast indicates that the performance of the children with reading disabilities exceeds that of the children without reading disabilities on the variable when the effects of WRAT–R Reading level and the other contrast are removed. The second contrast reflects the comparison between poor readers with and without an aptitude–achievement discrepancy. The coding for this contrast is +1 for Group 3, −1 for Group 2, and 0 for Group 1. A positive beta weight for this contrast indicates that Group 3 children outperform Group 2 children on the variable when the effects of WRAT–R and the other contrast are removed. Results consistent with a developmental-lag model of reading acquisition would be indicated if significant variance was explained by WRAT–R reading level but by neither of the contrasts. This would be an indication that overall reading level is associated with performance on the criterion variable but not with how quickly the subject attained that reading level (Groups 2 and 3 vs. Group 1) nor the level of intelligence of the poor reading groups (Group 2 vs. Group 3). Such a pattern is consistent with the prediction of the developmental-lag model that subject classification should be irrelevant once the reading level of the subject is taken into account. Conversely, if either of the contrasts is significant in the simultaneous equation from which WRAT–R Reading level has been partialed, then this would falsify the prediction of the developmental-lag model by indicating that the criterion variable is associated with something more than reading level alone—in this case, either how quickly the subject attained that reading level (Groups 2 and 3 vs. Group 1), the level of intelligence of the poor reading groups (Group 2 vs. Group 3), or both.

Illustrating the Method: Arithmetic Performance

To demonstrate the logic of the analytic technique, we analyzed performance on the Arithmetic subtest of the WRAT–R. Table 2 displays the mean WRAT–R Arithmetic grade equivalent scores for each of the three groups at each of five WRAT–R reading levels formed by grouping children at each reading level from 1 through 5. It can be seen that there is a tendency for the older Group 2 and Group 3 children at WRAT–R grade levels 2 through 5 to outperform the younger Group 1 children on arithmetic. Furthermore, there is a tendency for children in Group 2 to outperform the children with lower IQs in Group 3. Both of these tendencies are reflected in the results of the regression analysis conducted on the WRAT–R arithmetic scores. The linear component of WRAT–R reading level attained a multiple correlation of .572 when entered as the first predictor. There was also a significant quadratic trend, $F(1, 664) = 13.1$, $p < .001$, which raised the multiple correlation to .583. Although WRAT–R Reading grade level accounted for most

Table 2
Arithmetic Grade Level Means as a Function of Reading Subject Classification and Reading Grade Level on the Wide Range Achievement Test—Revised (WRAT–R)

	Group 1		Group 2		Group 3	
Variable	*M*	*n*	*M*	*n*	*M*	*n*
Arithmetic grade level (WRAT–R)						
Reading Grade Level 1	1.7	3	1.8	81	1.5	22
Reading Grade Level 2	2.1	42	2.8	91	2.2	34
Reading Grade Level 3	2.7	67	3.8	42	3.5	33
Reading Grade Level 4	3.3	80	4.4	43	3.4	17
Reading Grade Level 5	3.7	74	4.9	24	4.4	14

Note. Group 1 consists of children without an aptitude–achievement discrepancy who are reading at the level expected for their grade (controls). Group 2 comprises children with reading disabilities and high aptitude (with a discrepancy). Group 3 is composed of children with reading disabilities and low aptitude (without a discrepancy). n = number of subjects.

of the explained variance in WRAT–R Arithmetic scores, both contrasts had significant beta weights when entered simultaneously after WRAT–R Reading level. The positive sign on the beta weight for the Groups 2 and 3 versus Group 1 contrast, .278; $F(1, 662) = 68.8$, $p < .001$, indicates that the older children with reading disabilities outperformed the younger control children on arithmetic even when the effect of WRAT–R Reading level was controlled (as well as the other contrast). The negative sign on the Group 3 versus Group 2 contrast, −.124, $F(1, 662) = 16.28$, $p < .001$, indicates that the Group 2 children outperformed the Group 3 children when the effects of WRAT–R Reading levels (and the other contrast) are controlled. The latter trend is fairly small in absolute magnitude (accounting for just 1.5% unique variance), but it was detected statistically because of the large sample size ($n = 667$) in this particular analysis.

Pseudoword Reading and Spelling

One of the most well replicated findings in reading disability research is that, compared with chronological-age controls, children with reading disabilities have difficulty reading pseudowords (e.g., Bruck, 1990; Perfetti, 1985; Perfetti & Hogaboam, 1975; Siegel & Ryan, 1988; Snowling, 1981). It has been more difficult to determine whether children with reading disabilities display deficits compared with reading-level controls, but a recent meta-analysis by Rack et al. (1992) appears to indicate that this is the case. Whether this finding applies to Group 3 as well as Group 2 is less well established, and we explore this issue here. Our battery of tasks contained the following measures of pseudoword reading and spelling.

Goldman, Fristoe, and Woodcock pseudoword spelling. The children were administered the Spelling of Symbols subtest of the Goldman, Fristoe, and Woodcock (1974) Sound Symbol Test (GFW). Each child was asked to write pseudowords (e.g., *tash, chid,* and *plen*) that were read aloud by the examiner. Any acceptable phonetic equivalent was scored as correct. For example, the sound of *imbaf* could be spelled *imbaf, imbaff.* Before spelling the word, the child was asked to repeat it to ensure that he or she had heard it correctly. Mispronunciations were corrected. The reliability reported in the test manual is .90 (Goldman et al., 1974).

GFW pseudoword reading. The children were administered the Reading of Symbols subtest of the GFW Sound Symbol Test, which involves the reading of pronounceable nonwords. The reliability reported in the test manual is .85 (Goldman et al., 1974).

Woodcock Word Attack. The Word Attack subtest of the Woodcock Reading Mastery Tests, which involves reading pronounceable nonwords, was administered. This version of the Woodcock was administered at a later time to groups of children who had not been administered the GFW pseudoword reading test. The split-half reliability (Spearman–Brown corrected) reported in the test manual (Woodcock, 1987) is .94, .91, and .89 for the first, third, and fifth grade, respectively.

Experimental Pseudowords 1. The stimuli in this set were the following 32 pseudowords: *dite, mive, nowl, vake, gove, bave, fote, gick, vone, yate, bome, sice, tace, koes, hant, zale, cint, hode, woth, tood, jope, pame, gead, zool, kear, lipe, voal, tays, kade, bage, pute,* and *yaid.* Some of the pseudowords were derived from word bodies that had one pronunciation (the *ake* in *vake*), and some of the pseudowords were derived from word bodies that had alternative pronunciations (the *ave* in *bave*). For the purposes of this analysis, both the regular and the exception pronunciation of the nonword were scored as correct. The split-half reliability (Spearman–Brown corrected) of performance on the task was .87.

Experimental Pseudowords 2. The stimuli in this set were the following 18 pseudowords: *fody, dastle, sinth, buide, inswer, honot, sugan, womat, galace, risten, domach, lagon, puscle, farage, tepherd, meart, leopark,* and *pongue.* The pseudowords were derived from words that had irregular pronunciations (e.g., *sugar, answer*) and had been used in a study by Manis, Szeszulski, Howell, and Horn (1986). For the purposes of this analysis, both the regular and exception pronunciation of the nonword were scored as correct. The split-half reliability (Spearman–Brown corrected) of performance on the task was .92.

In the analyses that follow, the raw score on the GFW and Woodcock subtests and the number correct on the Experimental Pseudoword tests were used. Table 3 displays the mean performance on each of the pseudoword tests for each of the three groups at each of five WRAT–R reading levels. There was a consistent tendency for Groups 2 and 3 to perform less well than Group 1 at all reading levels and on all the tasks. In contrast, there were few systematic differences between Groups 2 and 3. The results of the regression

Table 3
Pseudoword Processing Performance as a Function of Subject Classification and Reading Grade Level on the Wide Range Achievement Test—Revised

	Group 1		Group 2		Group 3	
Variable	*M*	*n*	*M*	*n*	*M*	*n*
GFW pseudoword spelling						
Reading Grade Level 1	—	0	1.0	4	1.2	6
Reading Grade Level 2	9.7	18	4.2	12	6.9	15
Reading Grade Level 3	15.9	19	9.4	5	11.0	8
Reading Grade Level 4	16.0	17	10.8	10	10.0	6
Reading Grade Level 5	23.1	23	17.6	11	23.3	4
GFW pseudoword reading						
Reading Grade Level 1	—	0	1.6	5	1.0	6
Reading Grade Level 2	7.3	18	7.1	12	6.3	16
Reading Grade Level 3	23.6	18	19.1	7	12.7	9
Reading Grade Level 4	27.6	17	24.0	10	21.5	6
Reading Grade Level 5	41.3	23	31.9	11	36.0	5
Woodcock word attack						
Reading Grade Level 1	18.7	3	4.0	78	2.3	18
Reading Grade Level 2	16.9	26	14.2	75	6.2	22
Reading Grade Level 3	22.8	41	19.0	37	15.6	30
Reading Grade Level 4	28.2	53	26.4	24	22.8	16
Reading Grade Level 5	32.1	50	24.7	12	29.4	12
Experimental Pseudowords 1						
Reading Grade Level 1	21.0	2	7.9	37	5.8	6
Reading Grade Level 2	24.2	5	18.9	35	15.8	9
Reading Grade Level 3	26.5	15	23.6	19	19.5	12
Reading Grade Level 4	28.4	11	25.1	14	25.0	3
Reading Grade Level 5	30.0	13	25.8	5	27.2	5
Experimental Pseudowords 2						
Reading Grade Level 1	5.5	2	2.2	36	1.2	6
Reading Grade Level 2	12.6	5	6.6	34	5.0	9
Reading Grade Level 3	11.9	15	9.7	19	9.2	12
Reading Grade Level 4	13.9	11	10.6	14	9.0	3
Reading Grade Level 5	15.4	13	11.6	5	13.6	5

Note. GFW = Goldman, Fristoe, and Woodcock (1974) Sound Symbol Test. Group 1 consists of children without an aptitude–achievement discrepancy who are reading at the level expected for their grade (controls). Group 2 comprises children with reading disabilities and with discrepancy. Group 3 is composed of children with reading disabilities and low aptitude (without a discrepancy). n = number of subjects in each group.

analyses conducted on the pseudoword reading and spelling tests are displayed in Table 4. The linear components of WRAT–R reading level and all significant higher order polynomials accounted for a substantial proportion of the variance in all cases. However, in all five of the analyses, the Groups 2 and 3 versus Group 1 contrast had a significant negative beta weight, indicating that the older children with reading disabilities performed worse than the younger children without reading disabilities. Only two of the Group 3 versus Group 2 contrasts attained significance (Woodcock Word Attack and Experimental Pseudowords 1). The negative beta weight on this contrast indicated that Group 2 outperformed Group 3. However, the beta weight was small in absolute magnitude (–.098 and –.091, respectively), and this contrast accounted for only 0.8% unique variance after the variance explained by WRAT–R reading level and the other contrast had been extracted. Overall, although there was a consistent tendency for children with reading disabilities to underperform when compared with statistically matched reading-level controls on pseudoword tasks, the pseudoword processing differences between children with reading disabilities and average IQs and those with low IQs were either small or nonexistent.

More Tests of Phonological Coding Skill

There were two more tests of phonological coding skill in our battery that were different from the previous pseudoword tasks in that they did not require overt production of a pronunciation or a spelling. If the production requirement of the pseudoword tasks is critical, then it might be expected that group differences would be smaller on the following two tasks that did not require overt pronunciation.

Phonological choice task. This task was adapted from the work of Olson et al., (1985). The subject viewed pairs of pseudowords (e.g., *kake–dake* and *joak–joap*) and indicated which pseudoword sounded like a real word when pronounced. Thus, there is some lexical involvement in the task. However, because the stimulus pairs are both nonwords and the only way to respond correctly is to recode the stimuli phonologically, the task taps phonologically recoding skill but does so without the overt pronunciation required in pseudoword reading. There were 26 trials (chance performance is 13 correct), and the raw number correct was used in the analysis that follows. The split-half (odd–even) reliability of the task (Spearman–Brown corrected) was .68.

Pseudoword recognition (Gates–McKillop). Children were administered the Recognition of the Visual Form of Sounds subtest of the Gates–McKillop Reading Diagnostic Tests (Gates & McKillop, 1962). In this task, a nonword such as *wiskate* is read to the child who is then asked to select the correct version of the word from among four printed choices: *iskate, wiskay, wiskate,* and *whestit.* The maximum score on the task is 20. The reliability reported in the test manual is .80 (Gates & McKillop, 1962).

Table 5 displays the mean performance on the two phonological coding tasks for each of the three groups at each of the five WRAT–R reading levels. There appear to be few systematic differences among the groups. This impression is confirmed by the results of the regression analyses. For the phonological choice task, only the linear component of the WRAT–R scores was statistically significant (R = .605). When the two contrasts were entered into the regression equation, neither the Groups 2 and 3 versus Group 1 contrast, –.066, $F(1, 208) = 1.06$, nor the Group 3 versus Group 2 contrast, –.014, $F(1, 208) = 0.06$, was statistically significant. Similar results were obtained for the pseudoword recognition task. Here, both quadratic and cubic trends of the WRAT–R reading scores were significant (R = .812). However, when the two contrasts were entered into the regression equation, neither the Groups 2 and 3 versus Group 1 contrast, –.021, $F(1, 95) = 0.11$ nor the Group 3 versus Group 2 contrast, –.041, $F(1, 95) = 0.44$, was

Table 4
Regression Results for the Pseudoword Reading and Spelling Tasks

Task	GFW pseudoword spelling	GFW pseudoword reading	Woodcock word attack	Experimental Pseudowords 1	Experimental Pseudowords 2
			Dependent variables		
		R			
WRAT–R grade level	.618**	.807**	.727**	.751**	.751**
Quadratic fit	—	—	.733**	.802**	.773**
		β in final equation			
Groups 2 and 3 vs. Group 1 contrast	–.226**	–.145**	–.175**	–.206**	–.252**
Group 3 vs. Group 2 contrast	.068	–.033	–.098**	–.091*	–.044
		Unique variance explained			
Groups 2 and 3 vs. Group 1 contrast	.048	.019	.023	.034	.050
Group 3 vs. Group 2 contrast	.005	.001	.008	.008	.002
		F ratio in final equation			
Groups 2 and 3 vs. Group 1 contrast	13.06	9.52	26.20	19.27	26.06
Group 3 vs. Group 2 contrast	1.21	0.50	9.87	4.24	0.89
		Sample size			
n	158	163	497	191	189

Note. GFW = Goldman, Fristoe, and Woodcock (1974) Sound Symbol Test; WRAT–R = Wide Range Achievement Test—Revised. Group 1 consists of children without an aptitude–achievement discrepancy who are reading at the level expected for their grade (controls). Group 2 comprises children with reading disabilities and with discrepancy. Group 3 is composed of children with reading disabilities and low aptitude (without a discrepancy). Dashes indicate nonsignificant results.
* $p < .05$. ** $p < .01$.

statistically significant. Thus, unlike the case with pseudoword reading, performance level on these two tasks is a function of reading level only, and the rate of acquiring a given reading level (or the IQ of Groups 2 and 3) is not related to performance. In contrast, on pseudoword reading and spelling tasks for which an overt production of the stimulus was required, Groups 2 and 3 displayed a deficit when compared with Group 1.

Tests of Orthographic Coding Skill

Some previous research has suggested that children with reading disabilities are relatively less impaired at orthographic coding than they are at phonological coding (Frith & Snowling, 1983; Holligan & Johnston, 1988; Olson et al., 1985; Pennington et al., 1986; Rack, 1985; Siegel, 1993; Snowling, 1980). However, it is still unclear whether children with reading disabilities display an actual superiority in orthographic processing when compared with reading-level controls or whether their impairment in this domain is simply less severe when compared with their phonological coding deficit. If the former is the case, then the word recognition performance pattern of children with reading disabilities might be characterized as displaying compensatory processing: Compared with reading-level controls, superiority in one type of coding (orthographic) may be compensating for deficiencies in another type of coding (phonological). It seems that the logic of the reading-level match design and the previous finding of a phonological coding deficit (as measured by pseudoword reading) almost require a compensatory superiority in some other skill involved in word recognition. If pseudoword reading is indicative of a processing subskill that contributes to the ability to recognize words, and if children with reading disabilities perform more poorly than reading-level controls on this task, then they must have some other processing superiority that allows them to attain equivalent levels of word recognition. To test whether orthographic coding is indeed the compensatory mechanism, we examined performance on three different measures of orthographic coding skill. Another reason for focusing on orthographic coding skill is that connectionist theorists who have attempted to simulate aspects of reading performance (e.g., Seidenberg & McClelland, 1989; Van Orden et al., 1990) have tended to concentrate on tasks with a heavy phonological component. Few studies have contained a representation of orthographic tasks thorough enough to draw the attention of theorists constructing connectionist models. Our task battery contained three measures of orthographic coding skill.

Table 5
Phonological Coding Performance as a Function of Subject Classification and Reading Grade Level on the Wide Range Achievement Test—Revised

Variable	Group 1 *M*	Group 1 *n*	Group 2 *M*	Group 2 *n*	Group 3 *M*	Group 3 *n*
Phonological choice task						
Reading Grade Level 1	17.0	1	14.0	22	14.2	5
Reading Grade Level 2	15.0	10	15.3	26	15.6	9
Reading Grade Level 3	16.4	24	15.3	20	15.3	10
Reading Grade Level 4	19.2	33	17.5	8	18.4	7
Reading Grade Level 5	20.5	26	20.8	6	19.0	5
Pseudoword recognition						
Reading Grade Level 1	—	0	8.0	1	5.5	2
Reading Grade Level 2	12.7	15	11.4	5	12.6	7
Reading Grade Level 3	15.1	16	15.3	3	13.0	3
Reading Grade Level 4	17.1	13	18.3	7	16.0	2
Reading Grade Level 5	18.6	17	17.3	7	19.0	3

Note. Group 1 consists of children without an aptitude–achievement discrepancy who are reading at the level expected for their grade (controls). Group 2 comprises children with reading disabilities and with discrepancy. Group 3 is composed of children with reading disabilities and low aptitude (without a discrepancy). *n* = number of subjects in each group.

Spelling recognition. Subjects completed the Spelling subtest of the Peabody Individual Achievement Test (PIAT; Dunn & Markwardt, 1979). In the Spelling subtest, the child is required to recognize which of four alternatives represents the correct spelling of a word. Because the alternatives are minimally different (e.g., *time, teim, tihm,* and *tiem*), performance is facilitated if the subject has an accurate and complete orthographic representation of the stimulus stored in memory. The raw score on the test was used in the analyses that follow.

Experimental spelling recognition (two alternatives). This task was adapted from the work of Olson et al. (1985). The subject viewed pairs of letter strings that sounded alike (e.g., *rain–rane* and *boal–bowl*) and indicated which one was spelled correctly. Because the two strings sound the same when decoded, differences in phonological decoding ability cannot be the sole cause of performance differences on this task (indeed, it is possible that it is an interfering factor). Although subjects might still use phonological recoding to determine what word the two strings map into, the task requires that a lexical representation be examined. Thus, the task should to some extent reflect the accessibility and quality of orthographic entries in the lexicon. There were 26 trials (chance performance is 13 correct), and the raw number correct was used in the analysis that follows. The split-half reliability of the task (Spearman–Brown corrected) was .87.

Wordlikeness choice. In this task, the subject is shown two nonword strings (e.g., *filv–filk* and *lund–dlun*). They are told that neither string looks or sounds like an actual word but that one letter string is more like a word. One member of each pair contains an orthographic sequence that never occurs in English in that particular position in a word (e.g., *filv* and *dlun*). The subject's score is the number of times that the nonword without the illegal or low-frequency letter string was chosen. Although this task undoubtedly implicates phonological coding to some extent, the coding of frequent and infrequent orthographic sequences in memory should be a substantial contributor to performance. There were 17 trials and the raw number correct was used in the analysis that follows. There were no practice trials. The split-half reliability of the task (Spearman–Brown corrected) was .70.

Table 6 displays the mean performance on the three orthographic coding tasks for each of the three groups at each of the five WRAT–R reading levels. Table 7 displays the results of the regression analyses. Not surprisingly, WRAT–R Reading grade level was the dominant predictor of performance on each of the three tasks. However, its association with performance on the PIAT Spelling Recognition (R^2 = .60) measure was much stronger than its association with performance on the wordlikeness choice task (R^2 = .35). Unlike the analyses of the pseudoword tasks, in two of the three analyses (PIAT Spelling Recognition and Wordlikeness Choice), the contrast between children with and without reading disabilities displayed a positive regression coefficient (although only the former was statistically significant), thus indicating that subjects with reading disabilities performed better than the subjects without reading disabilities on these two tasks when WRAT–R Reading grade level was controlled. This coefficient was significantly negative for the experimental Spelling Recognition task, although small (unique variance explained = 1.3%). The word alternatives in this task were all short, high-frequency words. It is

Table 6
Orthographic Coding Performance as a Function of Subject Classification and Reading Grade Level on the Wide Range Achievement Test—Revised

Variable	Group 1 *M*	*n*	Group 2 *M*	*n*	Group 3 *M*	*n*
Spelling recognition (PIAT)						
Reading Grade Level 1	—	0	18.7	3	18.7	3
Reading Grade Level 2	23.8	5	29.0	2	26.2	6
Reading Grade Level 3	29.6	5	33.8	4	33.6	8
Reading Grade Level 4	35.7	17	32.5	2	38.7	9
Reading Grade Level 5	39.5	10	48.3	3	45.0	4
Experimental spelling recognition						
Reading Grade Level 1	20.1	1	16.3	21	15.4	5
Reading Grade Level 2	15.8	11	19.9	25	18.6	10
Reading Grade Level 3	22.9	24	21.7	20	18.2	10
Reading Grade Level 4	23.8	33	21.6	8	23.1	7
Reading Grade Level 5	24.6	26	25.3	6	24.8	5
Wordlikeness choice						
Reading Grade Level 1	10.0	1	10.4	28	11.0	8
Reading Grade Level 2	12.0	5	12.0	32	10.8	6
Reading Grade Level 3	13.5	14	13.8	17	14.4	10
Reading Grade Level 4	13.4	7	14.5	13	15.7	3
Reading Grade Level 5	13.6	12	13.8	4	15.3	4

Note. PIAT = Peabody Individual Achievement Test. Group 1 consists of children without an aptitude–achievement discrepancy who are reading at the level expected for their grade (controls). Group 2 comprises children with reading disabilities and with discrepancy. Group 3 is composed of children with reading disabilities and low aptitude (without a discrepancy).

possible that, compared with the other two tasks, the two-alternative Spelling Recognition task might not require orthographic representations to be as elaborated and accurate. Nevertheless, collectively, the data from these three tasks indicate that the reading-level deficits of children with reading disabilities are reduced on orthographic processing tasks.

The contrast between poor readers with and without an aptitude–achievement discrepancy did not attain significance in any of the analyses. As was the case with virtually all of the phonological coding tasks, Group 3 performed in a manner that was remarkably similar to that of Group 2 when overall word recognition level was controlled.

Spelling–Sound Regularity Effect

The finding of relative differences in orthographic and phonological coding suggests that perhaps the same relative pattern in processing skills might be demonstrated on different types of English words. For example, it would seem that the so-called spelling–sound regularity effect would provide a converging pattern. Indeed, several theorists (Barron, 1981; Castles & Coltheart, 1993; Olson et al., 1985; Manis, Szeszulski, Holt, & Graves, 1990; Treiman & Hirsh-Pasek, 1985) have suggested that the regularity effect should be an indicator of the differential functioning of phonological and orthographic coding skills. Many investigators have argued that this seems to follow from the classic dual-route model (Barron, 1986; Carr & Pollatsek, 1985; Coltheart, 1978; Humphreys & Evett, 1985) of lexical access:

> From the perspective of the dual-access model, the regular word advantage may be due to the fact that these words can be read by means of both the phonological and orthographic mechanisms, whereas irregular words can only be correctly pronounced by memorizing a word-specific association between print and pronunciation (i.e., using the orthographic mechanism).... The regularity effect provides an index of subjects' use of spelling-to-sound correspondences to pronounce familiar words. If dyslexic children are less able to apply their knowledge of these correspondences, they should show smaller regularity effects than normal readers. (Manis et al., 1990, pp. 229–230)

> The regular words are presumed to be processed by both the phonological and orthographic paths, while the exception words are confined to the orthographic path. In this model, disabled readers should show a smaller regular word advantage because their phonological coding is uniquely deficient. (Olson et al., 1985, p. 18)

> "If the less skilled readers are slower in activating phonological information than the skilled readers, then phonological information would be less likely to influence word recognition. As a result, they should be less likely than skilled readers to be faster on regular than exception words" (Barron, 1981, p. 305)

However, the empirical literature is puzzling, because although some studies have found the expected interaction between subject group and spelling–sound regularity (Barron, 1981; Beech & Awaida, 1992; Frith & Snowling, 1983; Snowling et al., 1986), an even larger number of studies using reading-level controls have not (Baddeley, Logie, & Ellis, 1988; Beech & Harding, 1984; Ben-Dror, Pollatsek, & Scarpati, 1991; Bruck, 1990; Holligan & Johnston, 1988; Olson et al., 1985; Stanovich et al., 1988; Treiman & Hirsh-Pasek, 1985; Watson & Brown, 1992). All of these studies have used the traditional matched-groups design. Here we examine the issue using a different analytic strategy.

The subjects were asked to name 36 regular (e.g., *gave* and *few*) and 36 irregular words (e.g., *have* and *sew*) taken from Baron (1979). Since the publication of Baron's (1979) article, theories of lexical access have evolved markedly. Most theories now emphasize the concept of *spelling–sound consistency*, which more accurately suggests a continuous dimension of spelling–sound predictability than does the use of such terms as *regularity* or *exception* (Barber & Millar, 1982; Glushko, 1979; Patterson & Coltheart, 1987; Patterson & Morton, 1985; Rosson, 1985; Venezky & Massaro, 1987). We retain the term *spelling–sound regularity*, however, to maintain consistency with past usage in the literature on reading disability. The issue of spelling–sound regularity or consistency is a complex one that has spawned voluminous research (Brown, 1987; Henderson, 1982, 1985; Humphreys & Evett, 1985; Kay & Bishop, 1987; Patterson, Marshall, & Coltheart, 1985; Rayner & Pollatsek, 1989; Rosson, 1985; Seidenberg, Waters, Barnes, & Tanenhaus, 1984; Venezky & Massaro, 1987). We are aware of the various controversies in this field (e.g., Stanovich, 1991b), but we address none of them here. For the purpose of the descriptive individual differences analysis that is our focus, it is necessary only to establish that these sets of words vary in their spelling–sound predictability, regardless of how they are defined (for example, whether by small-unit regularity or large-unit consistency; see Patterson & Coltheart, 1987), and that these words are comparable to those used in other investigations that have used the reading-level matched design (e.g., Treiman & Hirsh-Pasek, 1985).

Table 8 displays the mean performance (as percentage correct) on the regular and exception words. Also displayed in the table is the magnitude of the regularity effect for each of the three groups

Table 7
Regression Results for Orthographic Coding Tasks

Task	Dependent variables: Spelling recognition (PIAT)	Experimental spelling recognition	Wordlikeness choice
	R		
WRAT–R grade level	.775**	.670**	.524**
Quadratic fit	—	.686**	.568**
Cubic fit	—	—	.591*
	β in final equation		
Groups 2 and 3 vs. Group 1 contrast	.222**	−.121*	.107
Group 3 vs. Group 2 contrast	.006	−.021	.061
	Unique variance explained		
Groups 2 and 3 vs. Group 1 contrast	.041	.013	.009
Group 3 vs. Group 2 contrast	.000	.000	.003
	F ratio in final equation		
Groups 2 and 3 vs. Group 1 contrast	8.95	5.32	2.20
Group 3 vs. Group 2 contrast	0.01	0.14	0.83
	Sample size		
n	81	212	164

Note. WRAT = Wide Range Achievement Test—Revised; PIAT = Peabody Individual Achievement Test. Group 1 consists of children without an aptitude–achievement discrepancy who are reading at the level expected for their grade (controls). Group 2 comprises children with reading disabilities and with discrepancy. Group 3 is composed of children with reading disabilities and low aptitude (without a discrepancy). Dashes indicate results that are not significant.

at each of the five WRAT–R reading levels. Table 9 displays the results of the regression analyses. The first two analyses were conducted using performance on the regular and exception words, respectively, as the criterion variable. Not surprisingly, because the criterion variables reflect the ability to recognize words, WRAT–R Reading grade level accounted for most of the variance. Nevertheless, the Groups 2 and 3 versus Group 1 contrast did attain significance in the exception word analysis. Although the sign of the beta weight is in the expected direction (indicating superior performance by Groups 2 and 3 on exception words) it is very small (accounting for only 0.5% unique variance). The essential similarity in the performance of children with and without reading disabilities is bolstered by the separate regression analysis conducted on the magnitude of the regularity effect. Here, neither of the subject-group contrasts is statistically significant. Overall, there is little indication in these results that disabled readers are relatively more impaired at reading regular words than exception words. Although this finding is theoretically problematic, it is consistent with the results from some other studies that have used a discrete-groups reading-level matched design (e.g., Beech & Harding, 1984; Ben-Dror et al., 1991; Olson et al., 1985; Treiman & Hirsh-Pasek, 1985). Finally, differences in performance between Group 2 and Group 3 were negligible in all three analyses.

Analyzing Performance Outside of the Phonological Core: Working and Short-Term Memory

The processes analyzed so far have all been subcomponents of the word recognition (and spelling) process. Differences between children of differing IQs with reading disabilities on these component word recognition subskills have been extremely few in number. However, the phonological-core variable-difference model of reading disability (see Siegel, 1992; Stanovich, 1988a, 1988b) predicts that such differences should increase as the processes examined become more central, less modular, and further removed from the phonological core. Therefore, we examined several working and short-term memory (STM) tasks with the analytic method previously described.

Short-term memory—letter span. The STM Letter–Span task was similar to that used by Shankweiler, Liberman, Mark, Fowler, and Fischer (1979), with some minor procedural differences. The individuals were shown cards with five letters on them. Half of the letter sets were composed of letters from the rhyming group B, C, D, G, P, T, V, and half of the stimulus sets were composed of letters from the nonrhyming group H, K, L, Q, R, S, W. There were seven trials of each type (rhyming vs. nonrhyming), and the order of trial type was intermixed and determined randomly. The stimuli were presented for 3 s, and the subject was required to write down the letters that had been on the card. Only letters recalled in the correct serial position were scored as correct. The results were virtually identical when scored without respect to order. Subjects were given separate scores for performance on the rhyming and nonrhyming sets (the maximum score for each was 35). A derived score was computed for each subject whereby performance on the rhyming sets was subtracted from performance on the nonrhyming sets. This score (rhyme effect) reflected the impact of the rhyming variable on each subject's performance.

Working memory—words. This working memory task was modeled on the procedure developed by Daneman and Carpenter (1980). The children were orally presented with sentences that were missing their final words (e.g., *in summer it is very ______, People go to see monkeys in a ______*). The children were instructed to supply the final word of the sentences and to remember the words that they supplied. After responding to each of the sentences in a set, the child was then required to repeat the words that he or she selected in the same order that the sentences had

Table 8
Performance on Regular and Exception Words and the Magnitude of the Regularity Effect as a Function of Subject Classification and Reading Grade Level on the Wide Range Achievement Test—Revised

Variable	Group 1		Group 2		Group 3	
	M	*n*	*M*	*n*	*M*	*n*
Regular words						
Reading Grade Level 1	—	0	0.0	1	0.0	1
Reading Grade Level 2	29.8	15	16.0	4	35.1	8
Reading Grade Level 3	66.8	19	70.1	4	65.0	5
Reading Grade Level 4	81.9	32	80.6	13	84.0	4
Reading Grade Level 5	90.1	23	91.7	9	84.3	3
Exception words						
Reading Grade Level 1	—	0	2.8	1	8.3	1
Reading Grade Level 2	21.7	15	22.9	4	32.3	8
Reading Grade Level 3	59.9	19	57.6	4	57.2	5
Reading Grade Level 4	76.8	32	75.0	13	83.3	4
Reading Grade Level 5	81.0	23	86.1	9	77.8	3
Regularity effect						
Reading Grade Level 1	—	0	−2.8	1	−8.3	1
Reading Grade Level 2	8.1	15	−6.9	4	2.8	8
Reading Grade Level 3	6.9	19	12.5	4	7.8	5
Reading Grade Level 4	5.1	32	5.6	13	0.7	4
Reading Grade Level 5	9.1	23	5.6	9	6.5	3

Note. Group 1 consists of children without an aptitude–achievement discrepancy who are reading at the level expected for their grade (controls). Group 2 comprises children with reading disabilities and with discrepancy. Group 3 is composed of children with reading disabilities and low aptitude (without a discrepancy). *n* = number of subjects in each group. Dashes indicate data not available.

been presented (scoring without regard to order produced virtually identical results). There were three trials at each of four set sizes (2, 3, 4, and 5); thus the maximum score on the task was 12. Task administration was stopped when the individual failed all the items at one level. To minimize word-finding problems, the sentences were chosen so that the word was virtually predetermined. None of the children experienced any difficulty in supplying the missing word.

Working memory—numbers. This task was designed to be analogous to the Working Memory–Words task and was similar to a task designed by Case, Kurland, and Goldberg (1982). The task required the subjects to count yellow dots from a field of blue and yellow dots for a series of cards and then recall the counts for each set in the correct order (scoring without regard to order produced virtually identical results). The dots were arranged in randomly determined irregular patterns on 5 in. × 8 in. (10.7 cm × 20.32 cm) index cards. There were three trials at each set size of 2, 3, 4, or 5 cards; thus the maximum score on the task was 12. Task administration was stopped when the individual failed all the items at one level.

Table 10 displays the mean performance on the memory tasks for each of the three groups at each of the five WRAT–R reading levels. Table 11 displays the results of the regression analyses. On the two versions of the STM task (rhyming and nonrhyming), there was a tendency for Group 2 to outperform the other two groups matched on reading level. This pattern was reflected in the regression analyses, which indicate significant negative beta weights for the Group 3 versus Group 2 contrast. Analyses on the magnitude of the rhyming effect yielded somewhat different outcomes. First, it is apparent from Table 10 that all three groups displayed inverted U-shaped functions relating the magnitude of the rhyming effect to reading level, as has been suggested in a study by Olson, Davidson, Kliegl, and Davies (1984) using a related task. Ceiling effects might also contribute to this trend. However, indications of ceiling effects were mild in our data. The distribution of scores on the nonrhyming letters was negatively skewed, but only slightly so (the index of skewness was −.196). Only seven of 640 subjects achieved the maximum score on the task.

Because the function relating reading level and the rhyming effect takes on an inverted U shape, it is misleading to draw conclusions from comparisons among Group 1, Group 2, and Group 3 conducted at a single reading level. The complexity of the inverted U-shaped function—and the tendency to draw conclusions from a single comparison reflecting only one slice through this complex function—probably accounts for some of the controversy surrounding individual differences in the rhyming effect in the reading literature (Bisanz et al., 1984; Hall, Wilson, Humphreys, Tinzmann, & Bowyer, 1983; Johnston, Rugg, & Scott, 1987; Shankweiler et al., 1979). It is necessary to sample across several reading levels, as in the present experiment, to understand group differences in the magnitude of the rhyming effect (see also Siegel & Linder, 1984). As Olson et al. (1984) argued, "This curvilinear relation complicates the use of rhyming errors in recognition tasks, or confusion from similar items in recall lists, as evidence for phonetic memory in older disabled and normal readers" (p. 202).

The regression analysis on the rhyming effect presented in Table 11 indicates a significant quadratic trend (because of the inverted U-shaped relationship trend), a significant negative beta weight for the Groups 2 and 3 versus Group 1 contrast (indicating larger rhyming effects for the control subjects), and no significant contrast between Group 2 and Group 3. The performance pattern revealed in the analysis of the rhyming effect was thus similar to that obtained on the pseudoword processing tasks: Children with reading disabilities performed differently from control children, but no differences between children with and without an aptitude–achievement discrepancy reached statistical significance. This finding may indicate that the rhyme effect is tapping into the same phonological deficit that is the cause of the alphabetic coding problems that are associated with reading disability.

The results from the two working memory tasks were fairly similar to those obtained from the STM task. Both regression analyses indicated positive beta weights for the Groups 2 and 3 versus Group 1 comparison (although only that for the Working Memory–Words task was statistically significant) and significant negative beta weights for the Group 2 and Group 3 comparison (indicating that Group 2 performed better than Group 3 when statistically matched on WRAT–R Reading level). Thus, in contrast to the situation with tasks reflecting word-level processing, in the domain of short-term and working memory, there are performance differences between children with reading disabilities at different IQ levels.

Analyzing Performance Outside of the Phonological Core: Language Tasks

In addition to memory tasks, our battery allowed for the investigation of another domain of processing that extended outside the phonological deficit known to be associated with reading disability. As a further test of one of the central predictions of the phonological-core variable-difference model, that processing differences associated with IQ-discrepancy should increase as the task requirements extend beyond phonological processing, we examined performance on a variety of language-processing tasks.

Table 9
Regression Results for Regular and Exception Words

Task	Regular words	Exception words	Regularity effect
	R		
WRAT–R grade level	.849**	.854**	.157
Quadratic fit	.914**	.920**	.170
Cubic fit	—	—	.281**
	β in final equation		
Groups 2 and 3 vs. Group 1 contrast	.021	.070*	−.106
Group 3 vs. Group 2 contrast	.022	.024	−.023
	Unique variance explained		
Groups 2 and 3 vs. Group 1 contrast	.000	.005	.011
Group 3 vs. Group 2 contrast	.000	.001	.001
	F ratio in final equation		
Groups 2 and 3 vs. Group 1 contrast	0.35	4.25	1.56
Group 3 vs. Group 2 contrast	0.36	0.49	0.08
	Sample size		
n	141	141	141

Note. WRAT = Wide Range Achievement Test—Revised. Group 1 consists of children without an aptitude–achievement discrepancy who are reading at the level expected for their grade (controls). Group 2 comprises children with reading disabilities and high aptitude (with a discrepancy). Group 3 is composed of children with reading disabilities and low aptitude (without a discrepancy). Dashes indicate that results were not significant.
$^{*}p < .05$. $^{**}p < .01$.

Illinois Test of Psycholinguistic Abilities (ITPA)—Grammatical Closure. In this test (Kirk, McCarthy, & Kirk, 1968), the child is required to supply the missing word in a sentence read aloud. Thirty-three sentences were presented, along with pictures. The following are examples of stimuli: "*Here the man is planting a tree. Here the tree has been* ______." "*Here the thief is stealing the jewels. Here the jewels have been* ______." The raw score on the task was used in the analyses that follow. Internal consistency reliabilities for the task ranged from .60 to .74 across the age range tested in this study (Paraskevopoulos & Kirk, 1969).

Sentence Correction Task 1 and Task 2. In Sentence Correction Task 1, the child heard 21 sentences (see Willows & Ryan, 1986) and was given instructions to correct the error in them. The sentence could be repeated several times if the child wished. Five of the sentences involved correcting the meaning of an anomalous sentence (e.g., "*The moon is very big and bright in the morning*"). The remaining 16 sentences involved grammatical corrections such as incorrect verbs (e.g., "*The mailman should have taked the letter today*"); lack of agreement (e.g., "*The lion and tiger lives in the jungle*"); or incorrect function words, pronouns, and prepositions (e.g., "*Bill cried when he caught their finger in the door*"). The number of sentences that were transformed into a correct form was used in the statistical analyses that follow. In Sentence Correction Task 2, there were 20 sentences of the same type, but they were more difficult than those used in Task 1. All of the sentences used in Sentence Correction Task 2 involved grammatical corrections. The split-half reliabilities (Spearman–Brown corrected) of the two tasks were .77 and .86, respectively.

Oral Cloze Task 1 and Task 2. In Oral Cloze Task 1, 15 sentences with one word missing were read aloud, and the child was asked to supply the missing word in each sentence. The class (i.e., noun, verb, preposition, adjective, or conjunction) of the missing word varied across each sentence. The children were instructed to listen while the experimenter read aloud each sentence and were then asked to supply a word that would fit in that sentence. The experimenter said "blank" in place of the missing word. The following are examples of sentences: "*It blank very cold outside yesterday*" and "*Blank is at the door? he asked.*" The sentence could be repeated several times if the child wished. Few repetitions were requested. In Oral Cloze Task 2, there were 20 sentences of the same type, but they were more difficult than those used in Task 1. The number of sentences that were completed with semantically and syntactically acceptable words was used as a criterion variable in the analyses that follow. The split-half reliabilities (Spearman–Brown corrected) of the two tasks were .80 and .89, respectively.

Sentence repetition. The child was asked to repeat 10 sentences selected from Golick (1977). The following are examples of the sentences: "*The cat that the bird sees is in the tree*" and "*My mother left early and so did my father.*" The child was given practice repeating two simple sentences. The stimulus sentences were then read only once. To be scored as correct, the sentence had to be repeated exactly as heard. The split-half reliability (Spearman–Brown corrected) of the task was .77.

Table 12 displays the mean performance on the language tasks for each of the three groups at each of the five WRAT–R reading levels. Table 13 displays the results of the regression analyses. Across all six tasks, there was no strong tendency for children with reading disabilities to perform differently from reading-level controls. Two of the tasks (the more difficult versions of the sentence correction and oral cloze measures) displayed significant contrasts between Group 3 and Group 2. The negative sign of these two beta weights indicates that Group 2 performed better than did Group 3. There were no differences between these two groups on the grammatical closure task, sentence repetition task, Error Correction 1, and Oral Cloze 1.

Table 10
Mean Performance on Memory Tasks as a Function of Subject Classification and Reading Grade Level on the Wide Range Achievement Test—Revised

Variable	Group 1 *M*	Group 1 *n*	Group 2 *M*	Group 2 *n*	Group 3 *M*	Group 3 *n*
STM–rhyming						
Reading Grade Level 1	19.0	2	12.1	58	9.6	22
Reading Grade Level 2	13.6	42	15.7	71	12.1	35
Reading Grade Level 3	16.1	69	18.9	44	16.2	32
Reading Grade Level 4	17.5	98	21.1	33	19.2	19
Reading Grade Level 5	20.0	79	23.6	21	25.3	15
STM–nonrhyming						
Reading Grade Level 1	27.0	2	15.5	58	11.0	22
Reading Grade Level 2	18.2	42	19.3	71	16.0	35
Reading Grade Level 3	21.0	69	23.1	44	19.5	32
Reading Grade Level 4	22.8	98	24.7	33	20.3	19
Reading Grade Level 5	24.6	79	26.3	21	27.2	15
STM–rhyme effect						
Reading Grade Level 1	8.0	2	3.4	58	1.3	22
Reading Grade Level 2	4.5	42	3.7	71	3.9	35
Reading Grade Level 3	4.9	69	4.2	44	3.3	32
Reading Grade Level 4	5.3	98	3.6	33	1.1	19
Reading Grade Level 5	4.6	79	2.7	21	1.9	15
Working memory–words						
Reading Grade Level 1	4.5	2	2.8	54	1.6	16
Reading Grade Level 2	2.6	19	4.4	49	2.7	18
Reading Grade Level 3	3.0	31	4.7	28	3.8	21
Reading Grade Level 4	3.6	42	6.3	15	4.1	9
Reading Grade Level 5	4.6	35	7.6	7	4.0	8
Working memory–numbers						
Reading Grade Level 1	—	0	3.0	4	1.7	6
Reading Grade Level 2	3.1	12	3.8	6	2.4	9
Reading Grade Level 3	3.8	15	5.7	11	4.4	8
Reading Grade Level 4	4.8	28	4.0	1	4.5	6
Reading Grade Level 5	5.3	21	7.0	2	3.7	3

Note. STM = short term memory. Dashes indicate data are unavailable. Group 1 consists of children without an aptitude–achievement discrepancy who are reading at the level expected for their grade (controls). Group 2 comprises children with reading disabilities and with discrepancy. Group 3 is composed of children with reading disabilities and low aptitude (without a discrepancy). *n* = number of subjects in each group.

Replication Using Other Discrepancy Criteria

All of the analyses presented so far have been based on an absolute IQ-cutoff criterion to differentiate children with an aptitude–achievement discrepancy from those without a discrepancy. Here, we demonstrate that the patterns we have described are robust across different types of discrepancy criteria. The first alternative discrepancy criterion that we examine is the standard-score discrepancy cutoff. Although it has well-known psychometric deficiencies (e.g., Fletcher et al., 1992; McKinney, 1987; Pennington, 1986; Reynolds, 1985; Shepard, 1980; Wilson & Cone, 1984; Yule, 1984), the standard-score discrepancy method is widely used in research and is the most commonly used method in the United States of classifying children as having learning disabilities (Frankenberger & Fronzaglio, 1991).

As before, we selected all children who were reading at Grade Levels 1 through 5 on the Reading subtest of the WRAT–R. These children were classified into one of three categories. As before, Group 1 consisted of all children with percentile scores on the WRAT–R that were ≥30. Children with reading disabilities were defined as those who had percentile scores of ≤25 on the WRAT–R. These children were split into two groups on the basis of a comparison between their IQ scores and their standard scores on the Reading subtest of the WRAT–R (M = 100, SD = 15). Children in Group 2 had IQs that were more than 15 points higher than their WRAT–R standard scores (with a discrepancy). Group 3 comprised children whose IQs were not more than 15 points higher than their WRAT–R standard scores (without a discrepancy).

The results of regression analyses conducted on all of the criterion variables using the standard-score classification method are displayed in Table 14. This table displays the beta weights, significance levels, and proportion of variance explained for each of the two contrasts when they are in the final regression equation with WRAT–R reading scores (and all higher order WRAT–R trends that were statistically significant). The outcomes of these analyses closely parallel those conducted with the absolute IQ-cutoff criterion. Groups 2 and 3 performed worse than Group 1 on all five pseudoword processing tasks. Children with reading disabilities displayed performance commensurate with their reading levels on the two phonological coding tasks. They performed better than the controls on two of the three orthographic coding tasks (although only one of the contrasts attained statistical significance) and displayed spelling–sound regularity effects that were commensurate with their reading levels. More important, the results across these word-level processing tasks for the Group 2 versus Group 3 contrast paralleled the results obtained with the IQ-cutoff in that few differences were revealed. No beta weight exceeded .120 in absolute value, and on no word-level variable did the variance explained by the Group 3 versus Group 2 contrast exceed 1.2%. Taken as a whole, these results confirm the general conclusion drawn from our previous analysis: Children with reading disabilities with discrepancy and children with reading disabilities without discrepancy show similar performance on tasks tapping cognitive processes that underlie word recognition.

As in the previous analyses, differences between these subject groups became more apparent as the processes examined became more removed from the phonological core. Group 2 outperformed Group 3 on the WRAT–R Arithmetic subtest, on both STM tasks, and on both working memory tasks. The two groups did not differ significantly in the magnitude of the rhyme effect in STM, probably because this measure reflected the phonological processing deficit that they share. The results of the analyses conducted on the language-processing tasks mirrored the results obtained using the IQ-cutoff procedure. Group 2 significantly outperformed Group 3 on the Sentence Correction 2 and Oral Cloze 2 tasks. Coefficients for the Groups 2 and 3 versus Group 1 contrast were similar across the two methods of discrepancy classification.

The final criterion for discrepancy classification that we examined was a regression discrepancy criterion that is generally preferred to the standard-score discrepancy method (e.g., Fletcher et al., 1992; Reynolds, 1985). Although this method itself requires some complex decisions regarding the derivation of the regression equation (see Fletcher et al., 1992; Reynolds, 1985), for our purposes, most of these complications were not critical. The results were robust across various methods that we tried (deriving the equation from the normal sample, from norms, etc.).

The results presented in Table 15 were based on the following procedure for classifying Groups 2 and 3. The WRAT–R Reading percentile score was regressed on the IQ scores of all children in our sample who were between 7 and 16 years (84 to 203 months)

Table 11
Regression Results for Memory Tasks

Task	STM–rhyming	STM–nonrhyming	STM–rhyme effect	Working memory–words	Working memory–numbers
		R			
WRAT–R grade level	.526**	.474**	.053	.335**	.432**
Quadratic fit	—	.482*	.088*	—	—
		β in final equation			
Groups 2 and 3 vs. Group 1 contrast	.169**	.023	–.165**	.260**	.124
Group 3 vs. Group 2 contrast	–.129**	–.160**	–.069	–.263**	–.232**
		Unique variance explained			
Groups 2 and 3 vs. Group 1 contrast	.023	.011	.021	.050	.012
Group 3 vs. Group 2 contrast	.016	.025	.005	.065	.053
		F ratio in final equation			
Groups 2 and 3 vs. Group 1 contrast	21.11	0.35	13.89	23.08	2.07
Group 3 vs. Group 2 contrast	14.94	20.99	2.93	29.81	9.06
		Sample size			
n	640	640	640	354	132

Note. WRAT = Wide Range Achievement Test—Revised; STM = short-term memory. Dashes indicate that results are not significant. Group 1 consists of children without an aptitude–achievement discrepancy who are reading at the level expected for their grade (controls). Group 2 comprises children with reading disabilities and with discrepancy. Group 3 is composed of children with reading disabilities and low aptitude (without a discrepancy).
* $p < .05$. ** $p < .01$.

of age. The correlation between the WRAT–R Reading percentile and IQ in this group was .394. As before, we selected all children who were reading at Grade Levels 1 through 5 on the Reading subtest of the WRAT–R. Group 1 consisted of all children who had percentile scores on the WRAT–R of ≥30. All children with percentile scores ≤25 on the WRAT–R were considered as having reading disabilities. These children were split into two groups on the basis of the standardized residual scores that resulted from applying the regression equation from the entire 7–16 year-old sample. Group 2 comprised children whose standardized residual scores were less than –1.0, and Group 3 was composed of students whose standardized residual scores were greater than or equal to –1.0. As Fletcher et al. (1992) noted,

> In actuality, the regression cutoff is not a straight line, but a curve that bends downward at the ends. . . . The curvature in this line reflects imprecision in estimation of the population regression line. . . . In [our] plot, the regression cutoff is nearly straight because the number of cases used to compute the line was so large. (p. 557–558)

Likewise, our large sample rendered the choice between a curvilinear versus linear cutoff immaterial. Thus, we used the simpler, constant cutoff point of –1.0.

The results of regression analyses conducted on all of the criterion variables using the regression–discrepancy classification method are displayed in Table 15. Visual inspection immediately reveals that the outcomes of these analyses closely parallel those conducted with the absolute IQ-cutoff criterion and the standard-score discrepancy criterion. Children with reading disabilities performed worse than children without reading disabilities on all five pseudoword processing tasks. Children with reading disabilities displayed performance commensurate with their reading levels on the two phonological coding tasks. They displayed superiority on two of the three orthographic coding tasks and showed spelling–sound regularity effects that were commensurate with their reading levels. More important, the results across these word-level processing tasks for the Group 2 versus Group 3 contrast paralleled the results obtained with the other discrepancy criteria in that few differences were revealed. No beta weight exceeded .151 in absolute value, and on no word-level variable did the variance explained by the Group 3 versus Group 2 contrast exceed 1.7%.

As in all previous analyses, differences among these subject groups were revealed on the WRAT–R Arithmetic subtest, on both STM tasks, and on both working memory tasks. The results of the analyses conducted on the language-processing tasks paralleled the results obtained with the IQ-cutoff and standard-score discrepancy procedures. Coefficients for the Groups 2 and 3 versus Group 1 contrast were similar across all three methods of discrepancy classification.

In one final analysis we explored the relationships with a fully continuous regression model. That is, after removing WRAT–R reading grade level (and all significant higher order polynomials) we entered the WRAT–R percentile score and IQ score as continuous variables. Such an analysis asks a somewhat different question than the previous analyses using discrete contrasts. The discrete-contrast analyses are focused on explaining variance in a discrete classification of poor readers. Using WRAT percentiles and IQ scores as continuous variables we were able to focus on the issue of whether—across the entire continuum of performance—the rate of reading acquisition or the IQ of the reader is related to the criterion variable once the overall level of reading has been partialed. Specifically, a significant beta weight for the WRAT–R percentile in the final equation would indicate that the rate of reading acquisition is associated with the criterion variable even after the overall level of word-recognition skill and IQ are controlled. Likewise, a significant beta weight for IQ in the final equation would indicate

Table 12
Performance on the Language Tasks as a Function of Subject Classification and Reading Grade Level on the Wide Range Achievement Test—Revised

	Group 1		Group 2		Group 3	
Variable	*M*	*n*	*M*	*n*	*M*	*n*
Grammatical closure						
Reading Grade Level 1	—	0	19.4	7	16.9	8
Reading Grade Level 2	21.1	23	20.5	13	21.2	20
Reading Grade Level 3	23.9	35	28.0	11	24.3	7
Reading Grade Level 4	25.9	45	27.2	13	28.3	3
Reading Grade Level 5	28.1	36	31.1	10	28.7	3
Sentence Correction 1						
Reading Grade Level 1	—	0	8.0	2	4.5	2
Reading Grade Level 2	10.1	15	10.6	5	10.4	7
Reading Grade Level 3	10.8	19	13.6	5	9.0	4
Reading Grade Level 4	14.1	34	13.9	13	15.0	4
Reading Grade Level 5	14.5	25	15.3	9	14.7	3
Sentence Correction 2						
Reading Grade Level 1	—	0	9.8	4	4.2	5
Reading Grade Level 2	9.8	13	12.7	7	11.3	8
Reading Grade Level 3	14.4	17	14.7	12	13.6	8
Reading Grade Level 4	15.2	35	15.5	2	13.0	6
Reading Grade Level 5	16.6	27	16.0	2	13.0	3
Oral Cloze Task 1						
Reading Grade Level 1	—	0	7.0	2	3.3	3
Reading Grade Level 2	8.3	15	10.0	5	8.4	7
Reading Grade Level 3	10.2	19	10.8	5	9.8	4
Reading Grade Level 4	11.0	34	11.0	13	11.5	4
Reading Grade Level 5	11.2	25	11.9	9	12.0	3
Oral Cloze Task 2						
Reading Grade Level 1	12.5	2	9.1	61	6.8	14
Reading Grade Level 2	10.9	23	13.2	51	9.8	18
Reading Grade Level 3	13.9	33	14.2	31	12.0	21
Reading Grade Level 4	15.2	49	15.1	18	13.1	9
Reading Grade Level 5	15.6	43	17.4	7	14.3	8
Sentence repetition						
Reading Grade Level 1	—	0	4.5	2	4.3	3
Reading Grade Level 2	6.4	15	5.6	5	6.4	7
Reading Grade Level 3	7.2	19	9.2	5	6.5	4
Reading Grade Level 4	7.7	34	8.3	13	6.8	4
Reading Grade Level 5	8.2	25	8.8	9	9.3	3

Note. Dashes indicate data are not available. Group 1 consists of children without an aptitude–achievement discrepancy who are reading at the level expected for their grade (controls). Group 2 comprises children with reading disabilities and with discrepancy. Group 3 is composed of children with reading disabilities and low aptitude (without a discrepancy).

that IQ retains an association with the criterion variable independent of the level of reading acquisition or the rate of reading acquisition.

Table 16 displays the results of a series of such regression analyses. The table presents the beta weights (and unique variance explained) for WRAT–R percentile and IQ scores in the final regression equation with WRAT–R reading level (and all significant higher order polynomials). The analyses conducted on all five pseudoword tasks yielded significant positive beta weights for WRAT–R percentile. This finding indicates that independent of overall reading level and IQ, children acquiring reading skills at a faster rate (as indicated by their percentile score) were better at processing pseudowords. In contrast, WRAT–R percentile rank displayed few unique relationships with phonological coding, orthographic coding, and the regularity effect. IQ displayed few relationships with word-level processing variables once reading level and WRAT–R percentile had been statistically controlled. No beta weight for IQ exceeded .123 in absolute value, and on no word-level variable did the unique variance explained by IQ exceed 1.4%.

In contrast to the results on word-level processes, IQ was a unique predictor of performance on the memory tasks, on the language tasks, and on the arithmetic variable. WRAT–R percentile score was also a significant unique predictor on most of these tasks. However, its beta weight was negative in these analyses—in contrast to the positive sign on the beta weights in the pseudoword analyses. The negative beta weight is predictable from the overrepresentation of older subjects (who performed better on these tasks) at the lower WRAT–R percentiles in our sample. Finally, an interaction term (the product of WRAT–R percentile and IQ) was tested in all of the continuous analyses and was significant in only two: the Sentence Correction Task 2 (3.0% variance explained) and the Oral Cloze Task 2 (0.6% variance explained).

Discussion

The research conclusion that is at the heart of the phonological-core variable-difference model of reading disability (Siegel, 1992; Stanovich, 1988a) is that the critical processing deficit impairing the word recognition process of persons with reading disabilities lies in the phonological domain, a conclusion for which there is considerable converging evidence (e.g., Brady & Shankweiler, 1991; Bruck, 1992; Catts, 1991; Goswami & Bryant, 1990; Olson, in press; Olson et al., 1989; Pennington et al., 1990; Perfetti, 1985; Snowling, 1991; Vellutino & Scanlon, 1987). The results reported here add three important elaborations to this conclusion.

First, an earlier conjecture that this phonological core deficit would be more severe for children with reading disabilities and with an aptitude–achievement discrepancy (Stanovich, 1988a) appears to be false. Across seven comparisons conducted on different phonological coding tasks (see Tables 3, 4, and 5) and on the rhyme effect in STM (see Table 11), in only two cases was the Group 3 versus Group 2 contrast significant (on the Woodcock Word Attack and on the Experimental Pseudoword 1 measures) when the absolute IQ-cutoff criterion was used. However, the obtained coefficients were small (−.098 and −.091) and explained little unique variance (0.8% in both cases). Most important is that the sign of the coefficient is in the opposite direction of the prediction: children with a discrepancy outperformed the children without a discrepancy. Results from the analyses using a standard-score discrepancy criterion and from those using a regression discrepancy criterion were highly convergent.

As a whole, these results provide no support for the notion that there are critical differences between children with and children without an aptitude–achievement discrepancy in the phonological coding processes that are the proximal cause (see Gough & Tunmer, 1986) of their reading difficulties. Results from other studies converge with the present findings

Table 13
Regression Results for Language Tasks

Task	Grammatical closure	Sentence Correction 1	Sentence Correction 2	Oral Cloze Task 1	Oral Cloze Task 2	Sentence repetition
		R				
WRAT–R grade level	.615**	.529**	.553**	.518**	.596**	.376**
Quadratic fit	—	—	.584**	.584**	.628**	—
		β in final equation				
Groups 2 and 3 vs. Group 1 contrast	.109	.031	.001	.062	–.034	.035
Group 3 vs. Group 2 contrast	–.096	–.096	–.190**	–.099	–.236**	–.100
		Unique variance explained				
Groups 2 and 3 vs. Group 1 contrast	.010	.001	.000	.004	.000	.001
Group 3 vs. Group 2 contrast	.008	.009	.036	.009	.050	.010
		F ratio in final equation				
Groups 2 and 3 vs. Group 1 contrast	3.84	0.18	0.01	0.76	0.56	0.19
Group 3 vs. Group 2 contrast	3.39	1.74	8.32	1.99	34.69	1.59
		Sample size				
n	234	147	149	148	388	148

Note. WRAT = Wide Range Achievement Test—Revised. Dashes indicate results that are not significant. Group 1 consists of children without an aptitude–achievement discrepancy who are reading at the level expected for their grade (controls). Group 2 comprises children with reading disabilities and with discrepancy. Group 3 is composed of children with reading disabilities and low aptitude (without a discrepancy).
* $p < .05$. ** $p < .01$.

by indicating that children without a discrepancy demonstrate the same size of pseudoword reading deficit as do children with a discrepancy (Felton & Wood, 1992; Fredman & Stevenson, 1988; however, see Pennington et al., 1992). The failure of this key prediction of the phonological-core variable-difference model probably comes about because word recognition displays characteristics of acquired modularity (Humphreys, 1985; Perfetti & McCutchen, 1987; Seidenberg, 1985; Stanovich, 1990). The superior nonmodular, central processes of children with a discrepancy apparently do not compensate for their phonological coding deficits in any way, because their word recognition performance is exactly commensurate with the performance of children without a discrepancy who have the same level of word recognition skill. The processing skills and knowledge of children with a discrepancy apparently cannot penetrate the word recognition module to facilitate its efficiency. This may reflect a form of informational encapsulation related to that originally described by Fodor (1983).

The second way in which our results elaborate conclusions about the nature of the phonological coding deficits of children with reading disabilities is by indicating that differences in the type of phonological coding task determine the magnitude of the deficit that children with reading disabilities display when compared with statistically equated reading-level controls. The performance of children with reading disabilities was overpredicted by their WRAT–R Reading levels when the phonological coding task required overt pronunciation (pseudoword reading) or production (pseudoword spelling). However, when the phonological coding task did not require overt pronunciation or production (phonological choice task or pseudoword recognition), the performance of all children with reading disabilities was commensurate with their WRAT–R Reading levels.

The third way in which our results add to current canonical views about the word recognition processes of children with reading disabilities is by providing support for the hypothesis that a different balance of phonological and orthographic skills characterizes children with reading disabilities when they are compared with younger children without reading disabilities who are reading at the same level. On two out of three orthographic processing tasks (PIAT Spelling Recognition and wordlikeness choice) the performance of children with reading disabilities was underpredicted by their WRAT–R Reading levels, and this was equally true for children with and without an aptitude–achievement discrepancy. Whether low phonological coding ability is due to developmental lag, neurological insult, or whatever, one thing that children with reading disabilities, either with or without an aptitude–achievement discrepancy, have in common is the struggle with the reading task that school entry makes inevitable. It may be that the necessity of confronting the demands of the reading task while lacking phonological sensitivity triggers the reorganization of skills that we see in children with reading disabilities when they are compared with younger reading-level matched controls (see Snowling, 1987). Thus, the differential phonological and orthographic processing skills may be indicating a pattern of compensatory processing. This trade-off among relative strengths in the processing subskills of disabled readers is consistent with the suggestive theoretical and empirical evidence indicating

Table 14
Regression Results for Classification Based on Standard Score Discrepancy Method

Task	Groups 2 and 3 vs. Group 1		Group 3 vs. Group 2	
	β	Variance	β	Variance
Arithmetic grade level (WRAT–R)	.309**	.077	−.234**	.051
Pseudoword processing tasks				
GFW pseudoword spelling	−.258**	.057	.087	.007
GFW pseudoword reading	−.144**	.018	.003	.000
Woodcock word attack	−.157**	.019	−.093**	.007
Experimental Pseudowords 1	−.191**	.029	−.030	.001
Experimental Pseudowords 2	−.243**	.048	.002	.000
Phonological coding tasks				
Phonological choice task	−.061	.003	−.074	.005
Pseudoword recognition	−.025	.000	.071	.005
Orthographic coding tasks				
Spelling recognition (PIAT)	.222**	.035	.002	.000
Experimental spelling recognition	.007	.000	−.120*	.012
Wordlikeness choice	.095	.007	.019	.000
Regular and exception words				
Regular words	.014	.000	.014	.000
Exception words	.067	.004	−.006	.000
Regularity effect	−.111	.011	.037	.001
Memory tasks				
STM–rhyming	.201**	.033	−.160**	.024
STM–nonrhyming	.066	.003	−.194**	.035
STM–rhyme effect	−.148**	.018	−.066	.005
Working memory–words	.305**	.069	−.317**	.092
Working memory–numbers	.180	.020	−.156	.018
Language tasks				
Grammatical closure	.147*	.017	−.064	.003
Sentence Correction 1	.067	.004	−.082	.007
Sentence Correction 2	.097	.006	−.202**	.030
Oral Cloze Task 1	.104	.010	−.116	.013
Oral Cloze Task 2	.017	.000	−.269**	.063
Sentence repetition	.059	.003	−.007	.000

Note. Beta weights for each contrast for each variable are indicated along with proportion of variance explained. WRAT–R = Wide Range Achievement Test—Revised; GFW = Goldman, Fristoe, and Woodcock (1974) Sound Symbol Test; PIAT = Peabody Individual Achievement Test; STM = short-term memory. Group 1 consists of children without an aptitude–achievement discrepancy who are reading at the level expected for their grade (controls). Group 2 comprises children with reading disabilities and with discrepancy. Group 3 is composed of children with reading disabilities and low aptitude (without a discrepancy).
$^{*}p < .05$. $^{**}p < .01$.

that phonological and orthographic coding abilities are at least partially separable (Barker et al., 1992; Bowers & Wolf, 1993; Castles & Coltheart, 1993; Cunningham & Stanovich, 1990, 1993; McBride-Chang, Manis, Seidenberg, Custodio, & Doi, 1993; Stage & Wagner, 1992; Stanovich, 1992; Stanovich & West, 1989).

For most children with reading disabilities and a phonological deficit, a word recognition match with a younger group of children without reading disabilities seems to reveal a pattern of ability trade-offs: deficits in phonological sensitivity and in the phonological mechanisms that mediate lexical access, but relatively less impaired orthographic processing and storage mechanisms. Descriptively, it is important to be able to say that part of the phenotypic processing profile of readers with a disability is a differential pattern of phonological and orthographic coding skills. However, it is unclear how this differential pattern of subskills should be interpreted because this processing pattern is open to alternative interpretations. For example, it may be interpreted as an inherent processing ability that is less impaired in children with reading disabilities. Alternatively, it might be interpreted as a strategic choice—the product of consciously relying on other subskills in an attempt to overcome a phonological deficit. Another explanation might be related to attention. Perhaps because phonological coding is difficult, readers with a disability become very aware of the visual

Table 15
Regression Results for Classification Based on Regression Discrepancy Method

Task	Groups 2 and 3 vs. Group 1		Group 3 vs. Group 2	
	β	Variance	β	Variance
Arithmetic grade level (WRAT–R)	.301**	.073	–.235**	.051
Pseudoword processing tasks				
GFW pseudoword spelling	–.258**	.058	.099	.009
GFW pseudoword reading	–.149**	.020	.024	.001
Woodcock word attack	–.159**	.020	–.092**	.007
Experimental Pseudowords 1	–.185**	.027	–.014	.000
Experimental Pseudowords 2	–.240**	.046	.023	.000
Phonological coding tasks				
Phonological choice task	–.060	.003	–.084	.006
Pseudoword recognition	–.027	.001	.130*	.017
Orthographic coding tasks				
Spelling recognition (PIAT)	.212**	.033	.027	.000
Experimental spelling recognition	.010	.000	–.151**	.019
Wordlikeness choice	.102	.009	.059	.003
Regular and exception words				
Regular words	.014	.000	.015	.000
Exception words	.067	.004	–.003	.000
Regularity effect	–.110	.012	.039	.002
Memory tasks				
STM–rhyming	.197**	.031	–.147**	.020
STM–nonrhyming	.060	.003	–.174**	.028
STM–rhyme effect	–.150**	.018	–.052	.003
Working memory–words	.297**	.066	–.324**	.094
Working memory–numbers	.174	.020	–.155	.018
Language tasks				
Grammatical closure	.145*	.017	–.085	.006
Sentence Correction 1	.059	.003	–.042	.002
Sentence Correction 2	.122	.009	–.244**	.044
Oral Cloze Task 1	.103	.010	–.133*	.017
Oral Cloze Task 2	.010	.000	–.273**	.063
Sentence repetition	.059	.003	–.007	.000

Note. Beta weights for each contrast for each variable are indicated along with proportion of variance explained. WRAT–R = Wide Range Achievement Test—Revised; GFW = Goldman, Fristoe, and Woodcock (1974) Sound Symbol Test; PIAT = Peabody Individual Achievement Test; STM = short-term memory. Group 1 consists of children without an aptitude–achievement discrepancy who are reading at the level expected for their grade (controls). Group 2 comprises children with reading disabilities and with discrepancy. Group 3 is composed of children with reading disabilities and low aptitude (without a discrepancy).
$^{*}p < .05$. $^{**}p < .01$.

sequential redundancy in words. Finally, it is possible that readers with a disability maintain word recognition levels equal to younger controls without a disability—despite inferior phonological coding skill—because they have had more exposure to print (Cunningham & Stanovich, 1990; Stanovich, 1993a; Stanovich & Cunningham, 1992, 1993; Stanovich & West, 1989). In short, children with a reading disability may require more exposure to words to reach a given level of word recognition skill. Thus, when tested on an orthographic coding task that relies heavily on the quality of stored orthographic representations, readers with a disability do better because they have had more exposure to words (and hence letter patterns) than have younger children who reached that level of word recognition in less time. Such an explanation puts a somewhat different interpretation on the notion that orthographic and phonological coding are compensatory processing mechanisms. In this case, the compensation comes not from some inherent processing superiority of readers with a disability but from an excess of exposure to external stimuli.

It would be interesting to see how easily a connectionist model of word recognition (e.g., Seidenberg & McClelland, 1989) could simulate this type of compensation by deleting hidden units or by lesioning the model but compensating by providing more exposure to words (see Brown, Loosemore, & Watson, 1993, for a related demonstration). Such an in-

Table 16
Regression Results for WRAT–R Percentage and IQ as Continuous Variables

Task	WRAT–R %		IQ	
	β	Variance	β	Variance
Arithmetic grade level (WRAT–R)	.453**	.135	−.218**	.042
Pseudoword processing tasks				
GFW pseudoword spelling	.270**	.052	−.044	.002
GFW pseudoword reading	.214**	.032	−.052	.002
Woodcock word attack	.151**	.014	.114**	.012
Experimental Pseudowords 1	.208**	.027	.065	.004
Experimental Pseudowords 2	.304**	.057	−.025	.000
Phonological coding tasks				
Phonological choice task	.043	.001	.108	.011
Pseudoword recognition	.014	.000	.078	.005
Orthographic coding tasks				
Spelling recognition (PIAT)	−.196*	.021	.027	.000
Experimental spelling recognition	−.026	.001	.123*	.014
Wordlikeness choice	−.089	.005	−.045	.002
Regular and exception words				
Regular words	−.070	.003	−.013	.000
Exception words	−.114	.010	.013	.000
Regularity effect	.069	.004	−.078	.005
Memory tasks				
STM–rhyming	−.299**	.062	.229**	.048
STM–nonrhyming	−.199**	.027	.263**	.063
STM–rhyme effect	.076	.004	.094*	.008
Working memory–words	−.464**	.143	.389**	.143
Working memory–numbers	−.258	.047	.279**	.067
Language tasks				
Grammatical closure	−.246**	.043	.345**	.099
Sentence Correction 1	−.186*	.027	.324**	.089
Sentence Correction 2	−.085	.004	.217**	.039
Oral Cloze Task 1	−.163*	.021	.305**	.076
Oral Cloze Task 2	−.118**	.009	.375**	.132
Sentence repetition	−.070	.004	.278**	.065

Note. WRAT–R = Wide Range Achievement Test—Revised; GFW = Goldman, Fristoe, and Woodcock (1974) Sound Symbol Test; PIAT = Peabody Individual Achievement Test; STM = short-term memory.
* $p < .05$. ** $p < .01$.

vestigation might help to differentiate whether it is mere differential experience that accounts for this pattern or whether it is some experience-independent superiority in accessing orthographic representations that characterizes readers with dyslexia. Alternatively, a connectionist model with too many hidden units might be the appropriate neural model. Galaburda (1991) has suggested that the atypical symmetry in the planum temporale found in persons with dyslexia may be due to too many neurons rather than to too few. Interestingly, Seidenberg and McClelland (1989) noted that "it is known that in some cases, networks with too many hidden units 'memorize' the training examples, but fail to extract important regularities, and thus lack the ability to respond to novel inputs" (p. 561). Besner, Twilley, McCann, and Seergobin (1990, p. 435) suggested that too many hidden units may be the reason that the data simulations of certain connectionist models show lower nonword reading performance (just as in persons with dyslexia) than they should. If the phenotypic performance pattern of poor readers is indeed inferior phonological coding and superior orthographic coding as compared with reading-level matched younger controls, it may be that neurophysiological and connectionist models are converging on a coherent theory of why this is the case.

Paradoxical Regularity Effect

The results of applying our analysis to the reading of regular and exception words have added to the suggestion in the literature that some of the data patterns surrounding the regularity effect are seemingly paradoxical. Consider that we have found a different pattern of relative strengths in orthographic and phonological skills in children with reading disabilities; simultaneously, however, we have found that children with reading disabilities display spelling–sound regularity effects exactly commensurate with their reading levels. The classic dual-route models of word reading (e.g., Humphreys & Evett, 1985) can account for one or the other of these data patterns but not for both. The deficit on pseudoword processing tasks and relative superiority on orthographic tasks seems to indicate that their phonological routes are relatively more impaired and that the visual/orthographic route of children with reading disabilities operates more efficiently than that of reading-level matched controls. If this is the case, children with reading disabilities should have more difficulty with regular words, which are thought to implicate the use of the phonological route, and less difficulty with exception words, which are thought to require the use of the visual/orthographic route. Thus, children with reading disabilities should display smaller regularity effects than reading-level matched controls (Barron, 1981; Manis et al., 1990; Olson et al., 1985). In addition to ours, several studies have failed to find this expected data pattern (e.g., Beech & Harding, 1984; Bruck, 1990; Olson et al., 1985; Stanovich et al., 1988; Treiman & Hirsh-Pasek, 1985). Here, we have also demonstrated that the failure of this prediction occurs whether the sample with reading disabilities is defined using IQ discrepancy criteria or not.

It is possible that the falsification of this prediction derived from the dual-route theory might also have implications for connectionist models of the word-processing patterns of children with reading disabilities (e.g., Seidenberg, 1992; Seidenberg & McClelland, 1989; Van Orden et al., 1990). For example, consider the network used by Seidenberg and McClelland (1989) to simulate various well-known word-processing phenomena. The general connectionist architecture within which they conceptualized their studies is illustrated in Figure 1 (the unlabeled ovals represent the so-called "hidden units" that mediate between representational levels and that increase the computational power of the network). The smaller piece of this architecture that Seidenberg and McClelland actually simulated is shown in boldface type. In this model, visually presented words activate orthographic units, which in turn activate a set of hidden units, which activate phonological units. The hidden units also feed back activation to orthographic units. In addition to the connections displayed in the figure, the output of the 460 phonological units is interfaced with a system that constructs an articulatory-motor program, which is then executed by a motor system, thus enabling pronunciation. The 400 orthographic units are interfaced to response decision processes that play a role in tasks such as lexical decision. A learning algorithm adjusts the weights of units on the basis of the accuracy of the system's output through a process that is beyond the scope of this article.

Seidenberg and McClelland (1989) demonstrated that such a connectionist model can predict the Word Frequency × Regularity interaction for exactly the set of words used in the experiments that have observed the interaction (Seidenberg et al., 1984). Other even more subtle effects involving the consistency of the spelling–sound correspondences in a word's orthographic neighborhood are also predicted. The

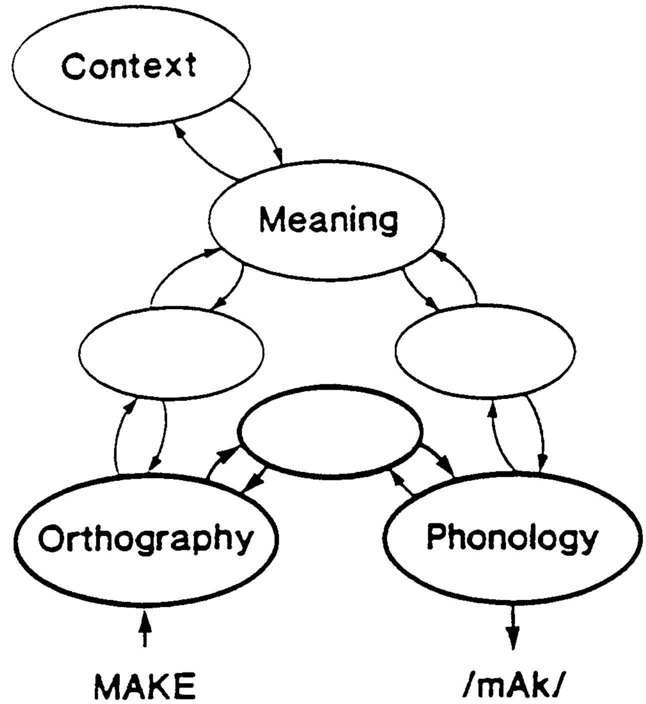

Figure 1. The general architecture of the parallel distributed processing model. (From "A Distributed, Developmental Model of Word Recognition and Naming" by M. S. Seidenberg and J. L. McClelland, 1989, *Psychological Review, 96,* p. 526. Copyright 1989 by the American Psychological Association. Reprinted by permission.)

network, as implemented, names regular and exception words by means of the same set of connections because it does not instantiate a meaning level. The model, as implemented, should have no difficulty simulating the finding of a pseudoword deficit on the part of readers with a disability because it can simply be assumed that the connection weights or number of hidden units are in some way suboptimal. However, a problem may arise when the pseudoword deficit is put together with the indication of equal regularity effects for children with reading disabilities when compared with the same reading-level controls that served as the baseline for the deficient pseudoword performance. This is because, in the Seidenberg and McClelland (1989) model, the same connections name words and pseudowords. Thus, the same lack of generalizing capacity that impairs the pronunciation of pseudowords might be expected to impair performance on regular words more than on exception words.

It may thus be necessary to implement the extended architecture (with a meaning level instantiated) illustrated in Figure 1 to account simultaneously for these two data patterns (children with reading disabilities displaying pseudoword deficits but, simultaneously, regularity effects equivalent to reading-level controls). Alternatively, however, Brown et al. (1993) have attempted to demonstrate that pseudowords challenge the generalizability of a connectionist network much more than the regularity effect; thus, a simple limitation in processing resources may well account for the two data patterns simply because they differentially stress the generalizing power of the network. Brown et al. (1993) successfully simulated the paradoxical data pattern by comparing networks differing in number of hidden units and practice (analogous to the comparison between older children with reading disabilities and younger children without reading disabilities). Brown et al. (1993) explained that

> the results demonstrate that the relative performance of the models with differing computational resources depends upon the performance metric that is adopted. Examining the difference between the models' error to regular and irregular members of the set to be learned does not show differences between systems with differing computational resources, while examining error to novel items does. It appears that nonword processing is a more sensitive measure of the generalisation capacity of a reading system than is the regularity effect. . . . Taking a computational approach has shown that nonword processing and regularity effects are not equally sensitive measures of generalisation capacity, and this is responsible for apparently inconsistent results in the literature. (pp. 5–6)

It remains to be seen whether their outcome will prove robust over a variety of implementation details and, thus, pertain to a broad class of connectionist models rather than just the one that they implemented.

Variable Differences Outside of the Word Recognition Module

The analyses conducted on the memory and language tasks test a critical prediction of the phonological-core variable-difference model of reading disability. In this model, performance differences between children with a reading disability who either have or do not have an aptitude–achievement discrepancy are predicted to increase as the processes tested become more central, less modular, and further removed from the phonological core (Siegel, 1992; Stanovich, 1988a). One way in which this prediction might fail, however, is if our conceptualization of the centrality and generality of the processes tapped by IQ tests is overestimated (Ceci, 1990; Siegel, 1989, 1993; Stanovich, 1993b). The entire structure of the model rests on assumptions regarding how well IQ tests tap reading-related processes of critical importance. Because many critiques of IQ tests have indicated that the cognitive domains that these instruments actually assess may be narrower than is commonly assumed (e.g., Ceci, 1990; Davidson, 1990), the confirmation of the predictions outlined here is far from assured.

The analyses presented in the current study provide moderate support for the predictions of the phonological-core variable-difference model. In an academic achievement domain other than reading, specifically, arithmetic skill, the children with an aptitude–achievement discrepancy outperformed children without a discrepancy, although the absolute magnitude of the difference was not large (an unweighted average across reading levels of 0.5 grade equivalents; see Table 2). Much stronger evidence for differential performance on nonmodular tasks operating across cognitive domains is found in the results of the memory tasks. Here there were robust differences between the two groups of subjects with reading disabilities on the STM–Letters task (for both rhyming and nonrhyming letters), the Working Memory–Words, and the Working Memory–Numbers task. Thus, there were differences between these two groups when the task involved primarily storage functions (STM–Letters) and when it implicated storage and capacity-demanding processing operations (working memory tasks). The beta weights for the Group 3 versus Group 2 contrasts were somewhat larger for the working memory tasks—as was the unique variance explained (6.5% and 5.3% versus 1.6% and 2.5%). Finally, three of the four overall Groups 2 and 3 versus Group 1 contrasts were significant (all but Working Memory–Numbers) and all had positive signs, indicating that WRAT–R Reading level underpredicted the performance of the older children with reading disabilities. This finding is probably reflective of the influence of maturational factors that are independent of reading development. Also, it should be emphasized that these comparisons are relative to reading-level controls. The performance of the children with a discrepancy would not be commensurate with chronological-age controls on most memory and language tasks (Siegel & Linder, 1984; Siegel & Ryan, 1988).

The results on the language tasks were less consistent than the results from the memory tasks. The Group 2 versus Group 3 contrast did not reach significance for either the grammatical closure or the sentence repetition task, although the sign of both coefficients indicated that the direction of the performance differences favored Group 2. The Group 2 versus Group 3 contrast also failed to reach significance in the analyses of performance on the easier versions of the sentence correction and oral cloze task although, again, Group 2 performed somewhat better than Group 3 on both tasks. On the more difficult versions of the sentence correction and oral cloze tasks the Group 2 versus Group 3 contrast was statistically significant. The sign of this coefficient in each of the 18 analyses conducted across the three different classification criteria was consistently negative (indicating superior performance by Group 2). In this respect, the analyses of the language tasks converged with the analyses of the memory tasks. Our results also converge with other studies, indicating that differences between Groups 2 and 3 emerge with greater frequency the farther one gets from the phonological core (Bloom, Wagner, Reskin, & Bergman, 1980; Das, Mensink, & Mishra, 1990; Ellis & Large, 1987; Jorm et al., 1986; Silva, McGee, & Williams, 1985).

Performance differences on the language tasks may be somewhat less robust because the phonological deficits that characterize children with and without an aptitude–achievement discrepancy may in fact disrupt performance on language tasks that ostensibly involved higher level language processing (Fowler, 1988; Mann, Shankweiler, & Smith, 1984; Shankweiler, 1989; Shankweiler, Crain, Brady, & Macaruso, 1992). However, such a view makes it difficult to explain why these readers with a disability outperformed statistically matched reading-level controls on the memory tasks—particularly the STM–Letters task and the Working Memory–Words task. Our pattern of findings may be more consistent with the view that reading disability should be conceptualized as residing on a continuum of developmental language disorder (Bishop & Adams, 1990; Catts, 1991; Gathercole & Baddeley, 1987; Kamhi, 1992; Kamhi & Catts, 1989; Scarborough, 1990). For example, Gathercole and Baddeley (1987) argued that

> although language problems are typically detected prior to the children receiving reading instruction . . . it is possible that the alphabetic literacy skills required in reading may be more sensitive to the adequacy of speech analytic skills than other aspects of normal linguistic development, such that a mild deficit may only be detectable in reading performance. More severe subjects may result in the more generalized symptom complex associated with developmental language disorder. . . . This is also clearly consistent with the notion that the two populations may quantitatively differ rather than qualitatively. (p. 464)

In the light of these attempts to conceptualize reading disability as a milder form of language disability, it is interesting to note that the question of whether a discrepancy-defined disability is different from a disability defined purely in terms of chronological age occurs in analogous form in the area of developmental language disorder (Aram, Morris, & Hall, 1992; Cole, Dale, & Mills, 1990). Cole et al. (1990) described how prior to more recent concerns about the relation between cognition and language

> Any child who demonstrated a discrepancy between chronological age and language age would generally have been considered a candidate for language intervention by speech–language pathologists. (p. 291)

However, an assumed tight link between language and cognition has recently led to what Cole et al. called the *cognitive referencing model*, which has the implication that

> Children who have developed language skills at a level equal to their cognitive skills are not considered to be language delayed, even if their language skills are significantly below chronological age. (p. 292)

However, just as in the area of reading disability, Cole et al. point out that

> it is surprising that there is little or no empirical evidence for evaluating the cognitive referencing model (p. 292).

Cole et al. (1990) conducted a study that compared the effect of a 1-year language intervention on discrepancy-defined and chronologically defined language-delayed children, and they found that the effects of the intervention were largely similar across a variety of language measures. In short, there was no differential response to treatment. Their failure to find an interaction with treatment in their study parallels our failure to find differences between Groups 2 and 3 in their pattern of phonological and orthographic coding skills.

Phenotypic Performance Pattern of Children With Reading Disabilities

We have provided a characterization of the phenotypic performance pattern of children with reading disabilities that we argue could serve as a benchmark for reductive research programs. No comparable study has included comparisons of children with reading disabilities who also either have or do not have an aptitude–achievement discrepancy across the range of reading levels and tasks that we have examined here. Although reading-level match designs have become much more common in the last 5 years, few studies have contained performance comparisons between children with and children without a discrepancy while simultaneously containing performance comparisons with reading-level matched controls (see Felton & Wood, 1992, for an exception).

An important strength of the data pattern we have described and of the framework we use to conceptualize the results—the phonological-core variable-difference model—is that it converges with other data in the literature. It thus provides a firmer foundation for reductive research efforts on reading disability (e.g., Pennington, 1991) that are examining the genetics of dyslexia, the heritability of reading subcomponents, neuroanatomical correlates, or performance patterns that can be mimicked by connectionist computer models. Many more group differences have been observed at the behavioral level than can be investigated by expensive and, thus, resource-limiting, neuroanatomical and genetic investigations. Investigators seeking relationships in a more fundamental scientific domain must have confidence that the data patterns that they are attempting to reduce are not spurious. The data patterns we have described were robust enough within our own investigation and display enough consistency when compared with other studies in the literature that they appear to have passed this initial threshold of confidence. Other investigations of group differences in the literature on reading disabilities literature, although deserving of further study, have not passed this threshold. Such is the case, for example, with data regarding visual processing deficits that have been reported in the literature (Lovegrove, 1992; Lovegrove, Martin, & Slaghuis, 1986; Willows, 1991). Although these findings do deserve experimental attention, their replicability has not been established (Hayduk, Bruck, & Cavanagh, 1992; Kruk, 1991), and they simply do not exist in the context of the converging evidence and theory that characterize our knowledge of phonological core deficits (Hulme, 1988; Shankweiler et al., 1992; Vellutino, 1979; Vellutino & Scanlon, 1987). Whether or not these visual deficits are eventually verified by converging evidence from a variety of laboratories, they are currently not the best candidates on which to focus reductive research techniques.

In summary, cognitive differences between children with reading disabilities who do or do not also have an aptitude–achievement discrepancy, all seem to reside outside of the word-recognition module. These differences are consistently revealed on memory tasks and in academic domains other than reading, and they are present but somewhat attenuated in language processing tasks. With regard to word recognition processes themselves, children with and without a discrepancy show performance patterns that are remarkably similar. Both show pseudoword reading performance below that expected on the basis of their WRAT–R Reading levels. Both show performance on phonological coding tasks not involving production of a spelling or pronunciation (phonological choice task and pseudoword recognition) that is commensurate with their reading levels but inferior to the reading level of chronological age controls. Children both with and without a discrepancy show indications of relative strength in orthographic processing skill: Performance on some orthographic tasks is underpredicted by their WRAT–R Reading levels. Both demonstrate spelling–sound regularity effects that are commensurate with their reading levels. We acknowledge that some of these performance patterns are better supported by converging evidence than others. For example, the overprediction of the pseudoword reading performance of children with and without a discrepancy by their reading level is well supported; whereas there is considerably less converging evidence for the notion of orthographic processing advantages among children with reading disabilities.

Contrary to previous conjectures (Stanovich et al., 1986; Stanovich et al., 1988), a developmental lag model in its strongest form does not fit the present results very well. That model predicts that once reading level is regressed out as a predictor of a reading-related cognitive subskill, subject categorization should not predict additional variance in the criterion variable. Only for the phonological coding tasks and the regularity effect was this the case. For all of the other tasks that we examined, at least one of the two contrasts was statistically significant. An advocate of a weakened version of the developmental lag model might argue, however, that on word-level processes, the maximum amount of unique variance explained by any categorization was 5.0%. Finally, it should be reiterated that we have evaluated these relative differences in performance patterns in terms of discrepancies from the performance of statistically equated reading-level controls. The children with reading disabilities would have shown deficits on virtually all tasks if their performance had been compared with the performance of chronological-age matched controls.

Importantly, the performance pattern we describe is extremely problematic for traditional conceptions of reading disability. As has been pointed out (e.g., Pennington et al., 1992; Taylor & Schatschneider, 1992), the idea of defining dyslexia by reference to an aptitude–achievement discrepancy gained credence because of the intuition that children with a discrepancy were more likely to have a distinct etiology. The idea that some poor readers were different from others in terms of the genetic or neuroanatomical underpinnings of their disability was what fueled the enthusiasm for IQ-discrepancy measurement. Measuring aptitude–achievement discrepancy was seen as a shortcut to the genetically and neurologically distinct group of poor readers that was assumed to exist. The discrepancy assumption survived for decades because there was no good evidence on the neurological, genetic, or phenotypic information-processing differences between children with and without a discrepancy. Our data undercut one component of the discrepancy assumption: Children with and without a discrepancy do not differ in the information-processing subskills (phonological and orthographic coding) that determine word recognition. IQ discrepancy does not carve out the unique information processing pattern in the word recognition module that is the primary indicator of reading disability. Likewise, recent genetic analyses have not indicated differential genetic causation for children with and without a discrepancy (Olson, Rack, Conners, DeFries, & Fulker, 1991; Pennington et al., 1992; Stevenson, 1991, 1992; Stevenson, Graham, Fredman, & McLoughlin, 1987). In short, neither the phenotypic nor the genotypic indicators of poor reading are correlated in any reliable way with IQ discrepancy. If there is a special group of children with reading disabilities who are behaviorally, cognitively, genetically, or neurologically different, it is becoming increasingly unlikely that they can be easily identified by using IQ discrepancy as a proxy for the genetic and neurological differences themselves. Thus, the basic assumption that underlies decades of classification in research and educational practice regarding reading disabilities is becoming increasingly untenable.

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